TRANSIT COOPERATIVE RESEARCH PROGRAM



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# TCRP Report 43

# Understanding and Applying Advanced On-Board Bus Electronics

Transportation Research Board
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# Report 43

# Understanding and Applying Advanced On-Board Bus Electronics

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*Subject Areas*

Public Transit

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TRANSPORTATION RESEARCH BOARD
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## TRANSIT COOPERATIVE RESEARCH PROGRAM

The nation's growth and the need to meet mobility, environmental, and energy objectives place demands on public transit systems. Current systems, some of which are old and in need of upgrading, must expand service area, increase service frequency, and improve efficiency to serve these demands. Research is necessary to solve operating problems, to adapt appropriate new technologies from other industries, and to introduce innovations into the transit industry. The Transit Cooperative Research Program (TCRP) serves as one of the principal means by which the transit industry can develop innovative near-term solutions to meet demands placed on it.

The need for TCRP was originally identified in *TRB Special Report 213—Research for Public Transit: New Directions,* published in 1987 and based on a study sponsored by the Urban Mass Transportation Administration—now the Federal Transit Administration (FTA). A report by the American Public Transit Association (APTA), *Transportation 2000,* also recognized the need for local, problem-solving research. TCRP, modeled after the longstanding and successful National Cooperative Highway Research Program, undertakes research and other technical activities in response to the needs of transit service providers. The scope of TCRP includes a variety of transit research fields including planning, service configuration, equipment, facilities, operations, human resources, maintenance, policy, and administrative practices.

TCRP was established under FTA sponsorship in July 1992. Proposed by the U.S. Department of Transportation, TCRP was authorized as part of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA). On May 13, 1992, a memorandum agreement outlining TCRP operating procedures was executed by the three cooperating organizations: FTA; the National Academy of Sciences, acting through the Transportation Research Board (TRB); and the Transit Development Corporation, Inc. (TDC), a nonprofit educational and research organization established by APTA. TDC is responsible for forming the independent governing board, designated as the TCRP Oversight and Project Selection (TOPS) Committee.

Research problem statements for TCRP are solicited periodically but may be submitted to TRB by anyone at any time It is the responsibility of the TOPS Committee to formulate the research program by identifying the highest priority projects. As part of the evaluation, the TOPS Committee defines funding levels and expected products.

Once selected, each project is assigned to an expert panel, appointed by the Transportation Research Board. The panels prepare project statements (requests for proposals), select contractors, and provide technical guidance and counsel throughout the life of the project. The process for developing research problem statements and selecting research agencies has been used by TRB in managing cooperative research programs since 1962. As in other TRB activities, TCRP project panels serve voluntarily without compensation.

Because research cannot have the desired impact if products fail to reach the intended audience, special emphasis is placed on disseminating TCRP results to the intended end users of the research: transit agencies, service providers, and suppliers. TRB provides a series of research reports, syntheses of transit practice, and other supporting material developed by TCRP research. APTA will arrange for workshops, training aids, field visits, and other activities to ensure that results are implemented by urban and rural transit industry practitioners.

The TCRP provides a forum where transit agencies can cooperatively address common operational problems. The TCRP results support and complement other ongoing transit research and training programs.

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The members of the technical advisory panel selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and while they have been accepted as appropriate by the technical panel, they are not necessarily those of the Transportation Research Board, the National Research Council, the Transit Development Corporation, or the Federal Transit Administration of the U.S. Department of Transportation.

Each report is reviewed and accepted for publication by the technical panel according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

To save time and money in disseminating the research findings, the report is essentially the original text as submitted by the research agency. This report has not been edited by TRB.

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# FOREWORD

*By Staff*
*Transportation Research Board*

*TCRP Report 43*, "Understanding and Applying Advanced On-Board Bus Electronics" will be of interest to transit managers, operations and maintenance professionals, bus procurement specialists, bus manufacturers and suppliers, and others interested in the application of advanced electronics to transit buses. The report provides an overview of electronics and its application to buses and other transportation sectors. The report then addresses electronic integration, potential benefits offered by integration, and transit agency experiences with the technology. The report concludes with guidelines for implementing transit bus electronics. It is intended to be a primer on the subject, providing essential background information to serve as a starting point for acquiring additional knowledge.

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The vast amount of electronics being incorporated into transit buses needs to be integrated in a way that takes full advantage of the technology. Advanced electronic systems have the ability to work together to perform a variety of functions to enhance bus operations, monitor equipment performance, diagnose technical problems, and provide important data to improve service efficiency and reduce operating costs. However, before such advantages can be realized, the industry needs to understand how electronic on-board systems function; determine the benefits such systems can offer; establish a standardized approach to system integration, data collection, and dissemination; and identify implementation requirements.

Under TCRP Project C-10A, research was undertaken by John J. Schiavone to (1) provide a basic level of understanding concerning advanced electronics and its application to transit buses; (2) describe how the application of electronics to individual components has improved their functionality; (3) describe how individual components can be integrated into larger systems to provide potentially greater benefits; (4) describe the experiences of a representative sampling of transit agencies that have integrated, or are planning to integrate, electronic technologies; and (5) offer a set of guidelines to (a) help transit managers and maintenance personnel decide if a given technology is appropriate for their operations, (b) plan procurement strategies for vehicles or components using advanced electronics, (c) prepare maintenance and training programs, (d) take full advantage of the technology's capabilities, and (e) manage the data generated from the equipment.

To achieve the project objectives, the researcher obtained information from a variety of sources, including 19 transit agencies employing various types of advanced on-board bus electronics. In addition, approximately 45 other relevant organizations were contacted, including bus manufacturers, suppliers, government agencies, and trade associations. A review of relevant technical literature was also conducted.

## AUTHOR ACKNOWLEDGMENTS

John J. Schiavone, Guilford, Connecticut, was responsible for the collection of data and preparation of this report. Assistance was provided by L.R. "Rich" Davis, Steven Barsony, Vincent DeMarco, and Lauren Dunlap of Davis & Associates.

The author acknowledges the valuable contributions made by representatives from transit agencies, bus and component manufacturers, systems integrators, and others who provided information for this report. Constructive assistance was also provided by individual Panel members and TCRP Program Officer Christopher Jenks.

# CONTENTS

# EXECUTIVE SUMMARY

Bus transit has entered a new era — the electronic era where equipment brings with it a new set of capabilities and challenges. This study provides a basic level of understanding to assist transit managers make better use of the technologies and to address the challenges.

The application of advanced on-board electronics has evolved in stages. Simple electronics such as transistors are first applied to improve the functionality and longevity of individual components. Electronics are then incorporated into control modules or "black boxes," capable of manipulating data to exert greater control over equipment. Electronic controls also have the ability to:

- Make data available to technicians to assist with diagnostics;
- Share data with other on-board equipment to collectively accomplish tasks that no single component could achieve individually;
- Transfer data back to the transit agency in real time to monitor operator, vehicle, and mechanical performance; and
- Store data for retrieval at a later time for further analysis.

The integration of electronic components has developed around three bus areas:

- Drivetrain Level where the engine, transmission, brakes and other components exchange data to improve driveability and safety;
- Electrical Level where the on/off nature of "hotel" devices such as lights and small electrical motors are controlled by a computer-based multiplexing system to streamline the electrical system for reduced complexity and bus weight; and the
- Information Level where radio communication, vehicle location, fare collection, passenger information, passenger counting, and other systems are integrated to improve the efficiency of moving passengers and the agency's own operation.

Each bus level has taken a separate approach to integration, which requires a data network based on specified rules or "protocols" to exchange data. A data network provides a framework whereby all components linked to the system speak and understand the same electronic language.

Electronic integration has evolved around three bus levels because there was, and still is, no practical network capable of joining all bus components into a single "system." Although integration is divided into three levels, gateway devices capable of translating electronic languages can be used to exchange data between levels.

In general, the networks used to integrate electronic components can be based on open or proprietary protocols. An open data communication protocol lies in the public domain, allowing any manufacturer to build components to comply with defined rules. Proprietary networks restrict network access to those licensed to use it. While open networks promote product interchangeability, proprietary networks tie users to specific products and limit choice.

The integration of Drivetrain Level components follows requirements established by the Society of Automotive Engineers (SAE) specifically for truck and bus applications. The requirements are formalized in a series of data networks (called standards) based on open communication protocols. J1708 was the first SAE standard used to integrate drivetrain components, followed by the more robust J1939 network needed to handle the complexity of anti-lock brakes and traction control. Every bus delivered to U.S. transit agencies today uses SAE data networks for drivetrain integration.

Electrical Level integration (i.e., multiplexing) is based on proprietary networks developed by firms specializing in machinery automation and aerospace technology. Since they are used primarily to control simple on/off type functions, the proprietary nature of the operating system itself does not affect the device being controlled. As a result, agencies can continue to purchase lamps, electric starter motors, and related switches from traditional sources.

Information Level integration is currently in a state of transition regarding the use of data networks. SAE J1708, modified to suit bus applications, is beginning to be specified by some agencies. In the past, however, systems were designed around proprietary networks.

While many support a vehicle area network (VAN) for Information Level integration based on J1708, others feel that it is too slow to handle data transfer to and from the agency in real time. Proponents of J1708 claim the radio is the limiting factor and, after evaluating several alternatives, have determined that J1708 is the most appropriate solution for bus applications. As the controversy continues, provisions in Transportation Equity Act for the 21st Century (TEA 21) may require provisional standards if transportation modes cannot decide on one.

Issues concerning on-board data exchange have also impacted heavy-duty trucking and rail transit. Through a Transportation Research Board (TRB) project, rail transit is developing a standardized approach to on-board data communication. More closely allied with buses is the truck, which serves as a model for electronic integration. A modern truck has about 10 computer-controlled systems, including vehicle location, radar crash avoidance, radio communication, equipment monitoring, and others. Like the drivetrain, each system exchanges data using a SAE J1708-based network. The approach gives fleet owners a variety of products to choose from, and saves the truck builder engineering time when accommodating the individual needs of fleet operators.

The trucking industry has progressed to the point where Information Level components are integrated into the overall vehicle design. With regard to transit buses, the integration is typically accomplished as retrofits to accommodate the many buses already in the fleet. In time, however, bus builders will need to take a more active role in designing their vehicles to accept this equipment as integral part of its design.

Electronic integration has the potential to provide many benefits. Some benefits are more "automatic" than others, coming to the agency with little if any effort. Examples include the many benefits offered by drivetrain and electrical system integration. For example, the engine, transmission, and retarder work in unison to improve driveability without requiring much intervention by the agency (i.e., up-front engineering or specification work). Multiplexing is also delivered to the agency as a complete system, engineered into the bus to streamline its electrical system.

Unlike drivetrain integration and multiplexing, Information Level components such as radio communication, vehicle location, fare collection, passenger information, and passenger counting systems are typically integrated into the bus after it is built. This retrofitting aspect requires agencies to invest a great deal of effort if tangible benefits are to be obtained. At one agency, the technical specification alone for its new radio and automatic vehicle location (AVL) system consists of nearly 400 pages.

Information Level integration is complex. Due to its virtual unlimited potential, agencies and vendors alike are continually finding new ways to apply the technology and reap benefits from it.

Applications have provided several significant benefits. Included are improved operator-to-agency communication, monitoring of key vehicle and operator performance indicators, improved passenger information, and fare data based on individual transactions.

While many successes have been actively promoted, comprehensive cost/benefit analyses to objectively access the value of these benefits are not yet complete. Furthermore, the many downside aspects to the implementations, caused by the technology and agencies applying it incorrectly, have been minimized. They include insupportable equipment, legal disputes, procurement delays, agencies receiving outdated equipment, and new equipment that does not perform as originally intended.

The ability to successfully implement Information Level technologies depends on many factors, including the agency's ability to:

- Thoroughly understand the technology and related issues;
- Develop a long-range plan that applies technology in a systematic manner to address specific needs;
- Write a specification that clearly identifies agency needs and how the technology is expected to address those needs;
- Train the staff to operate and maintain the equipment properly, and to deal with on-going software development programs to maximize the hardware's effectiveness;
- Anticipate the costs and organizational effort required to implement the technology;
- Manage all of the data generated from the integration;
- Use open data communication protocols to ensure product interchangeability, system expansion, and product availability;
- Understand that advanced equipment will have a limited shelf-life due to new technology advances and future industry standards and regulations; and
- Ensure that suppliers will provide adequate service and product support for the life of the equipment.

The need to have the above-mentioned factors in place cannot be overemphasized. The complexity and level of effort needed to apply Information Level technologies will test the ability of individual agencies, as well as the entire industry, to produce quantifiable benefits. To help meet this challenge, this study offers the following guidance to bus transit:

- Promote the understanding of electronic technologies and related issues in terms that the entire industry can comprehend;

- Create frank and open forums to objectively address and communicate all aspects of the technology, related issues, and experiences;
- Encourage bus builders to incorporate Information Level equipment into the overall vehicle design as is done in the automobile and trucking industries;
- Settle the controversy that exists over the SAE J1708-based VAN and adopt a suitable on-board standard for data exchange as quickly as possible to avoid the potential mandating of standards by TEA 21;
- Encourage additional agency representation especially from maintenance and operations, in the standards-development process to ensure that standards are, and continue to be, appropriate for bus transit;
- Determine how data generated from Information Level equipment can be used to benefit all agencies;
- Establish a peer review panel comprised of experienced bus transit representatives to review and assist transit agencies during planning and implementation phases;
- Consider expanding "White Book" specifications to create a standardized approach to electronic integration where data cables, plug-in component receptacles, and the communication protocol that on-board electronic components use to communicate are stipulated for use in a uniform and efficient manner; and
- Create an environment where agencies, suppliers, relevant government agencies, trade associations, and others all work in unison to provide the "organizational horsepower" needed to ensure that electronic integration provides quantifiable benefits in the most cost-effective manner possible.

# INTRODUCTION AND RESEARCH APPROACH

Electronics — no other technology has contributed more to the increased functionality and complexity of transit buses. When the Advanced Design Bus (ADB) was introduced in the late 1970s, solid state voltage regulators, alternator diodes and fluorescent lighting were virtually the only examples of on-board electronics. Fareboxes and destination signs with electronic controls appeared shortly afterwards as optional equipment. Today, electronics has become an integral part of every bus. Moreover, recent advances make it possible to combine electronic components and systems in unique and complex ways, providing benefits not possible with individual components.

Using electronics to combine or "integrate" components has the potential to help revitalize bus transit by offering passengers an enhanced level of service to compete with other transportation modes. However, as transit enters this new era of electronic application, it must address a new set of challenges if the technology is to succeed.

For one, the complexity involved with electronic integration can be confusing and difficult to keep pace with, especially for those accustomed to mechanical systems. The complexity is reduced when the bus builder integrates the equipment. For example, electronic drivetrain components are delivered as a fully integrated system. Integration of "information" components such as advanced radio and automatic vehicle location (AVL) systems, however, typically takes place after the bus is assembled. This retrofitting aspect requires a great deal of involvement and understanding by the transit agency if the system as a whole is to provide tangible benefits.

The need to understand thoroughly how evolving electronic technology can be applied to solve problems and enhance service cannot be overstated. Lack of understanding could hamper the technology's introduction, making it difficult to take full advantage of its capabilities, develop adequate maintenance programs, plan procurement strategies, initiate new training, and manage data generated by the equipment.

Another important challenge facing bus transit is the lack of industry-accepted standards to integrate the technology. While drivetrain integration has been standardized, other on-board devices are typically built around proprietary systems that often lock agencies into single suppliers and restrict interoperability.

Despite the "maintenance free" label given to electronics, components are bound to fail at times, especially when subjected to 12 or more years of bus service. Dirty conditions caused by constant passenger traffic and interior vacuums, vibration, moisture, fumes, and in some cases low-skilled technicians and inadequate specifications, can wreak havoc with electronics. When electronic systems do fail, untrained technicians will require new skills and tools to diagnose faults.

Fluctuations in funding can impede an agency's ability to provide the tools and skills needed to maintain on-board electronics. Inconsistent funding could also prevent agencies from implementing technology on a fleet-wide basis, leaving some buses without essential equipment. Additionally, lengthy procurement cycles can exacerbate the problem of technology becoming quickly outdated.

Of all the challenges facing transit today, converting the vast amount of data produced by on-board electronic equipment into useful information is arguably the most significant. Speaking at the 1997 APTA Annual Meeting, futurist Frank Feather stated "... In this new society, transit isn't about moving people. Now it's about managing and moving information about moving people." He emphasized that unless transit professionals keep up with the current technology they will become "roadkill on the information superhighway" (1). Although somewhat overstated, the point is clear — electronic technologies produce additional information that must be managed.

The many opportunities and challenges brought forth by the proliferation of bus electronics can be attributed to four major factors:

(1) The technology, much of which has proven itself reliable and beneficial in other transportation applications, is readily available and transferable for bus use.

(2) Agencies continually seek new bus features to benefit passengers, bus operators and their own operations and maintenance departments.

(3) Federal regulations calling for:

a) the reduction of heavy-duty diesel exhaust emissions (Environmental Protection Agency - EPA);

b) improved on-board communications to allow disabled passengers to be oriented to their destination (Americans with Disabilities Act - ADA); and

c) anti-lock brake systems (ABS) (Federal Motor Vehicle Safety Standards - FMVSS).

(4) Passage of the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), creating formal programs for Intelligent Transportation Systems (ITS) and Advanced Public Transportation Systems (APTS); and the Transportation Equity Act for the 21st Century (TEA 21), which continues ITS programs.

Much of the advanced electronics being applied to transit buses today has filtered down from aerospace, military and commercial aviation applications. The automobile industry, using motor racing as its test bed, was a pioneer in the development of advanced electronics for on-highway use. Today, automobiles have more computer power than the original Apollo spacecraft. Further, the use of electronics in auto racing has become so extensive that sanctioning bodies limit technology in some classes to shift the competitive emphasis back to human ability.

A few observations made from the use of electronics and computers in auto racing provide an interesting perspective to those in bus transit looking to apply the technology (2):

(1) There is no magic. Computers are tools invented, designed, manufactured and used by humans to do ordinary tasks quicker and easier.

(2) Computers do not replace humans. In fact, they have increased the number of people required to manage the additional information made possible by computers.

(3) It is computer software that really matters. Hardware consists of relatively simple and available components — the software is where the bulk of human creativity comes to bear.

## OBJECTIVES

For many in bus transit, gaining an understanding of advanced electronics is not an easy task. Available material tends to be narrowly focused around specific products and topics, making it difficult to grasp the entire subject. Additionally, much of the material promotes a particular product or program, making it difficult to obtain an unbiased viewpoint.

The objectives of this study are to:

(1) Provide a basic level of understanding concerning advanced electronics and its application to transit buses.

(2) Describe how the application of electronics to individual components has improved their functionality.

(3) Describe how individual components can be integrated into larger systems to provide potentially greater benefits.

(4) Describe the experiences of a representative sampling of transit agencies that have integrated, or are planning to integrate, electronic technologies.

(5) Offer a set of guidelines to assist transit managers and maintenance personnel:

a) decide if a given technology is appropriate for their operation;

b) plan procurement strategies for vehicles or components using advanced electronics;

c) prepare maintenance and training programs;

d) take fuller advantage of the technology's capabilities; and

e) manage the data generated from the equipment.

## APPROACH

The subject of electronics and its application to buses is extremely complex. This study is intended as a primer on the subject, providing essential background information to serve as a starting point for acquiring additional knowledge.

Information presented in this study was obtained-from a variety of sources including technical literature, telephone contacts, and site visits made to selected transit agencies and equipment suppliers. Due to its comprehensive nature, this study did not attempt to include the experiences of every transit agency. It does, however, provide a representative sampling of experiences to help guide others with their implementation efforts. A listing of transit agencies visited and contacted for this study is included in Appendix A.

## ORGANIZATION

This study begins by providing essential overview material on electronics and its application to buses and other transportation sectors. Later chapters address electronic integration, potential benefits offered by integration, and transit agency experiences with the technology. The study concludes with a set of guidelines for implementing on-board electronics.

To assist those seeking general information, each chapter begins with a summary that provides essential overview material. The summaries furnish a "big picture" look at the subject before addressing the details. They also provide an abbreviated method of reading the document.

The study is organized as follows:

*Chapter 1* addresses electronics in general terms and reviews the five stages of electronic application to buses.

*Chapter 2* describes how electronics has enhanced the functionality of specific bus components.

*Chapter 3* reviews electronic applications to other vehicles including automobiles, trucks and rail transit.

*Chapter 4* describes multiplexing, which uses proprietary data networks to integrate the control of basic on/off-type switching functions in the electrical system.

*Chapter 5* describes how standard data networks developed by the Society of Automotive Engineers (SAE) can be applied to integrate equipment in the Drivetrain and Information Levels.

*Chapter 6* summarizes key programs that support electronic integration including ITS, and programs that promote the exchange of data between ITS elements.

*Chapter 7* takes a broad look at the potential benefits that agencies can hope to achieve from electronic integration.

*Chapter 8* examines the experiences of a representative sampling of transit agencies applying electronics to buses.

*Chapter 9* takes all of the material gathered from the study and offers guidelines to consider when implementing on-board electronics.

# ELECTRONICS: OVERVIEW AND APPLICATION

This chapter provides an overview of electronics and its application to buses. Highlighted are the many advances made in a relatively short period of time.

## SUMMARY

Before addressing electronics, a distinction must be made between "electrical" and "electronic." An electrical system consists of (1) the framework that carries electrical battery current throughout the bus, and (2) the various devices that utilize that current. The electrical framework includes the batteries, wiring, wire connectors, relays and switches. Examples of electrical devices include incandescent lights, passenger stop chime, the engine's starter motor, and heating/ventilation fan motors.

To control these electrical devices, a series of electro-mechanical switches called relays are energized in response to an operator's command or other triggering action. For example, placing the gearshift lever in reverse energizes a relay that sends electrical current to the reverse lamps. Known as relay logic, the system requires individual hard wires traveling to relays and each device being controlled. As the number of control functions increased and became more complex, relay logic was found to be inadequate.

Electronic controls replace relay logic with solid state components that share information in serial data streams. The result is less wiring and the ability to control functions more efficiently. Electronics is an outgrowth of the transistor, invented in 1947 as a means of switching electrical power without moving parts, thus the term "solid state." Solid state electronics was first applied to improve the functionality of specific components. For example, the addition of solid state electronics to alternators and voltage regulators improved battery charging.

While the transistor was significant, it was the invention of the integrated circuit (IC) in 1958 that led to the commercialization of electronic products. Before the IC, there was no practical way of combining the myriad of components such as transistors, diodes and resistors into a cohesive package. The miniaturization of IC "chip technology" eventually led to the development of solid state control systems such as microprocessors and computers.

Packaged into what is referred to as electronic control modules (ECMs), ICs enable components to be controlled with increased speed, improved reliability and less power. Today, ECMs or "black boxes" enhance the operation of virtually every major bus system and accessory. ECMs are also capable of self calibration, self diagnostics and data storage — characteristics not possible with mechanical controls.

Fareboxes, destination signs, engines and transmissions were among the first bus components to apply electronic controls. Doors, multiplexed wiring systems, anti-lock brakes (ABS), air conditioning, automatic vehicle location (AVL) and other equipment followed.

As the evolution of electronics progressed, components were integrated into larger systems capable of performing more complex tasks because of their ability to share data. Component integration was made possible by the creation of data networks, a framework which establishes the protocol or "electronic language" that components use to exchange data.

In the next stage of on-board electronic development, data produced from components are transmitted to remote locations. This transfer of data can occur through a physical plug connection or radio frequency (RF) transmission. AVL systems, originally developed to monitor bus location, have been expanded to collect data from several on-board systems and broadcast that data to the transit agency and other locations.

In a future stage of electronic application, powerful computers using artificial intelligence will exert greater control over vehicles, such as radar-assisted steering and other vehicle control functions.

## ELECTRONICS: THE SECOND INDUSTRIAL REVOLUTION

The impact that electronics has had on nearly every facet of our life today would not be possible without the invention of the transistor in 1947 (3), and the integrated circuit (IC) in 1958 (4, 5). The transistor is a compact device used to switch direct current (DC) power, the type of electrical power used in transit buses. Transistors perform silently and have no moving parts — hence the term "solid state." As a replacement for vacuum tubes, the transistor offered many advantages including reduced size and weight, rugged char-

| *Parameter* | **ENIAC 1946** | **IBM PC-AT 1985** | **IBM ThinkPad 770 Notebook 1997** |
|---|---|---|---|
| *Size* | 3,000 Ft.$^3$ | 1.35 Ft.$^3$ | 0.16 Ft.$^3$ |
| *Power Consumption* | 140,000 Watts | 140 Watts | 20 a |
| *Program Storage* | 16K Bits | 40 Megabytes | 5,000 Megabytes |
| *RAM* | 1K Bits | 6K Bytes | 32 Megabytes |
| *Clock Rate* | 1 Megahertz | 6 Megahertz | 233 Megahertz |
| *Weight* | 60,000 lbs. | 50 lbs. | 7.8 lbs. |

*Table 1-1* ***Comparison of the 1946 ENIAC vacuum tube computer with a PC of the mid 1980s, and today's notebook PC.***

acteristics, long life, and the ability to operate at lower voltages with higher efficiency.

An IC is the general term used to describe the grouping of many electronic components (e.g., transistors, resistors, and diodes) into an extremely small space. ICs are classified by the number of elements they contain. A very large scale integrated circuit, for example, accommodates about 7.5 million elements in a space of about one square inch.

The development of the IC was important and timely because without it, the commercialization of solid state electronics would not be possible. Prior to the IC there existed no practical way of connecting the many electronic components in a compact, reliable and cost-effective package. The ongoing development and commercialization of solid state technology has become known as the "Second Industrial Revolution" or the "Electronic and Information Revolution."

### Circuit Integration Reduces Size, Increases Speed

Since first introduced over 30 years ago, ICs have become integrated into smaller and smaller units. What once was housed in large mainframes now fits into the palm of a hand. Each reduction in size has increased the speed of operation, improved reliability, and decreased power requirements.

The advancement of ICs can be illustrated by comparing the pre-transistor ENIAC vacuum tube computer of 1946 to personal computers (PCs) of the 1980s, and portable PCs of the 1990s. As Table 1-1 illustrates, the ENIAC of 1946 is no match for today's portable computer. Based on the electronic advances made during the past 50 years, one can only imagine what will transpire during the next half century.

### Microprocessors and Memory

The miniaturization of ICs, also referred to as "chip technology," produced two key elements essential to the development of solid state control systems: microprocessors and memories (6). Microprocessors are essentially computers that manipulate data using binary digits, or bits.

A bit is the smallest unit of memory available, representing data that only can be expressed as either on/off, true/false. A byte represents a grouping of eight bits that can store a numerical equivalent between 0 and 255. The larger numerical range expands data beyond simple on/off to include characters, analog values and text. Microprocessors typically process and store data in 16 bit groups, also known as "words."

Memory is where program and data files are stored and manipulated. There are two types of solid state memories: volatile and nonvolatile. Volatile memory can be easily altered or erased, and can be written to and read from. Without proper backup, however, power loss can destroy programmed contents. Random Access Memory (RAM) is the best known form of volatile memory. It is relatively fast and provides an easy way to create and store application programs.

Nonvolatile memory retains its contents even if power is lost and does not require a backup. Examples of nonvolatile memory include Read Only Memory (ROM), Electronically Programmable ROM (EPROM), and Electronically Erasable Programmable ROM (EEPROM).

### Microcontrollers and Microprocessors

As noted earlier, the IC led to the development of the microprocessor. Concerning bus applications, a distinction must be made between "Microcontroller" and "Microprocessor." The distinction is important because each has very different capabilities.

Electronic components such as engines and transmissions are controlled by microcontrollers, also referred to as ECMs. A microcontroller is a special-purpose processor with limited capabilities, designed to support specific tasks over the life of the component.

An engine, for example, uses an ECM to "read" inputs from various sensors and execute logic as prescribed by the application program to control fuel delivery. As conditions change (i.e., the engine warms up), fuel delivery also changes to optimize performance. The use of EPROMs and EEPROMs allows the component's operating characteristics to be changed to suit specific customer needs. Despite its ability to receive and send data to other components, an engine ECM is limited to drivetrain-related tasks.

A microprocessor, on the other hand, is a general purpose processor capable of supporting a wide range of peripheral devices and software applications. Microprocessors typically run DOS, Windows or Unix as an operating system and can be programmed to handle a wide variety of tasks based on user needs.

A vehicle logic unit (VLU) is an example of a microprocessor. The VLU can be configured to interface with several systems including the radio, AVL, and drivetrain components to perform a variety of tasks.

When customizing tasks, it is important to know where the task is housed. If the task is located within a device (i.e., ECM), functions are limited and custom applications may be restricted. Although an engine ECM can monitor vehicle mileage to calculate fuel economy, it can not be expanded to perform next-stop annunciator functions. As a general-purpose microprocessor, however, a VLU can store route data and combine it with other data to make announcements at specific locations on a given route.

## THE FIVE STAGES OF ELECTRONIC APPLICATION

### Background

Beginning in the 1970s, an increasing number of electronic devices were installed to enhance the functionality of bus components. In addition, the basic electrical system was increasing in size as a greater number of control features such as door interlocks and automatic climate control systems were added. The method used to control these devices is known as "relay logic." At the heart of this control system is the relay, a heavy-duty switch that directs electrical current to a particular device only when certain conditions exist. For example, the relay that allows a bus to kneel is only energized when the parking brake is applied. Achieving control through relay logic depends on numerous "hardwired" wire connections, each of which offers a potential for failure.

The advanced electronics discussed in this study replace most or all the relay logic with solid state components that share information in serial data streams. Use of solid state electronics to control functions not only reduces wiring and related components, but provides a more sophisticated degree of control possibilities.

### Stage 1: Simple Electronics Enhance Functionality

Solid state electronics first appeared on transit buses around the 1970s with the introduction of alternators, solid state voltage regulators, and transistorized radio communication. Adding simple electronics such as transistors and diodes (provides one-way current flow) to individual components represented the first stage of electronic development.

The progression of electronic application to buses is consistent with the five stages of development experienced in the automobile industry (7). Table 1-2 illustrates the five stages as applied to transit buses.

| | | |
|---|---|---|
| *Stage 1* | **SIMPLE** | Simple electronic features are added to improve the efficiency of vehicle components (i.e., solid state voltage regulator and transistorized two-way radios). |
| *Stage 2* | **COMPLEX** | Microcontrollers (i.e., ECMs) create new functions to further improve the functionality of individual components (i.e., electronically controlled engines, transmissions, destination signs and fareboxes). |
| *Stage 3* | **ON-BOARD INTEGRATION** | Integrated on-board electronic systems provide capabilities greater than the sum of individual sub-systems (i.e., engine, transmission and passenger door controls share information to determine vehicle speed, door position and current gear to provide safer travel and lower emissions). |
| *Stage 4* | **OFF-BOARD INTEGRATION** | On-board bus electronic systems communicate with the transit facility and other remote locations, integrating the vehicle into larger environmental systems (i.e., AVL, downloading of vehicle condition data at the service line; ITS applications for traffic signal priority, remote traveler information; etc.). |
| *Stage 5* | **"SUPER SYSTEMS"** | (Future) Integration of high-powered computers using artificial intelligence and fuzzy logic that will make the bus and its external environment more attuned and responsive to customer safety and comfort (i.e., automated steering and speed control for "hands-free" driving). |

*Table 1-2* *The application of bus electronics shown in five stages.*

### Stage 2: Electronic Controllers Improve Capabilities

In the second stage of electronic application, microcontrollers (i.e., ECMs) were added to expand the control capabilities of individual components. The use of ECMs began to escalate during the 1980s with the introduction of electronic fareboxes and destination signs. Propelling electronics into the drivetrain area were increasingly stringent exhaust emission regulations for heavy-duty diesel engines. Today, ECMs are used in virtually every major bus component including engines, transmissions, air conditioning, doors, brakes, and lighting.

The benefits obtained from electronics far exceed those possible from mechanical, pneumatic, hydraulic, and electro-mechanical controls. Characteristics of electronic controls such as speed, accuracy, reliability, self-calibration, and ease of replacement simply can not be duplicated by mechanical means. Additionally, built-in diagnostic features make electronic components easier to maintain.

Figure 1-1 illustrates the evolution of bus electronics throughout the last three decades.

### Stage 3: Integration Links Components Into Larger Systems

The third stage involves the integration of electronic-controlled components into larger systems to perform more complex functions, providing additional benefits to transit agencies. Integration is made possible through the use of data networks that allow individual components to "communicate" with one another. All devices connected to the network transmit and receive data from other devices, using the data collectively to sense, monitor, and control various vehicle functions. The exchange of data allows components to interact automatically without operator intervention.

One of the first examples of component integration involved the sharing of data between the engine and transmission to improve shift quality. When the transmission sends information over the network that it is about to make a gear change, the engine can momentarily reduce its torque output to make the shift a smoother one — all without operator intervention. Other examples of integration made possible by data networks include:

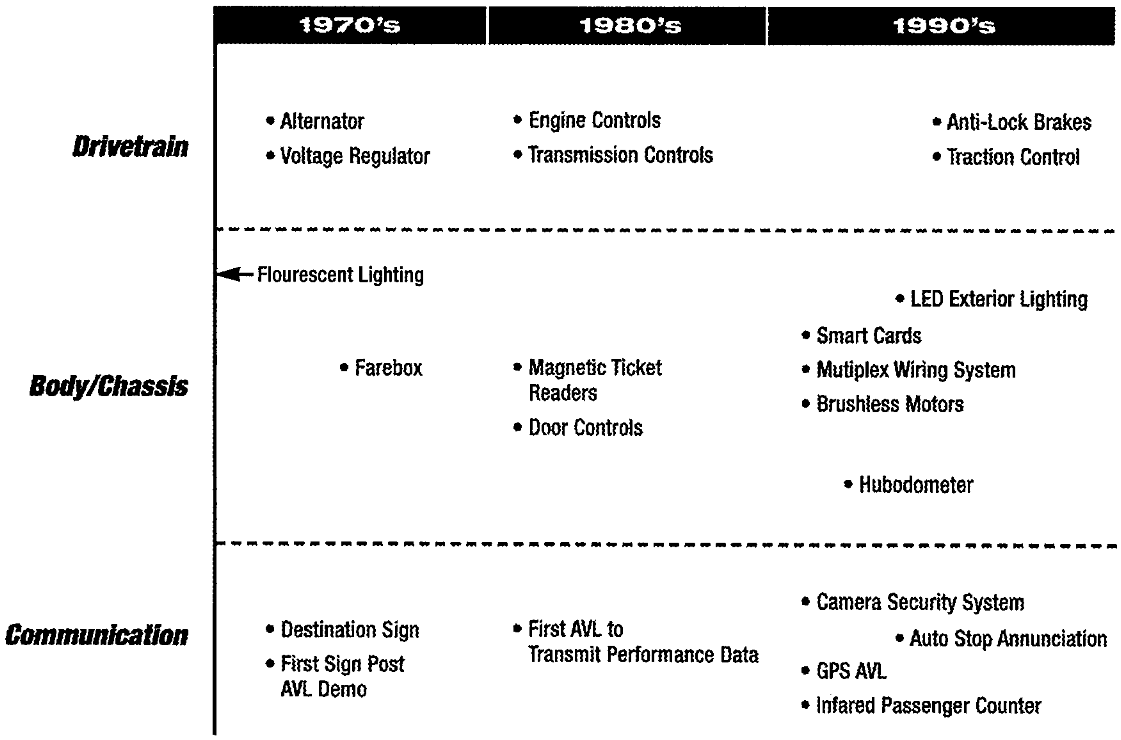


*Figure 1-1* *Evolution of bus electronics during the last three decades.*

- Combining engine and anti-lock brake data to create traction control;
- Use of a single key pad to control the farebox, destination sign, and automatic stop annunciator;
- Combining passenger counters, destination signs, AVL, and other electronic devices to provide detailed information concerning fare and passenger trends;
- Use of a data network and microprocessor to control electrical devices such as lights, horn, etc. (i.e., multiplexing); and
- Exchanging vehicle speed and door position information to activate passenger door interlocks.

The degree to which components can exchange data depends on whether the network is based on standard (i.e., open) or proprietary (i.e., closed) communication protocols. Fully open data networks allow components made by different manufacturers to be used interchangeably on the network (i.e., in a "plug and play" fashion). An analogy would be the personal computer (PC) where keyboards, monitors and software programs from different suppliers can all be used interchangeably. Conversely, fully closed systems are restricted to specific products licensed to use the network. Additional information on data networks is provided in Chapter 5.

### Stage 4: Off-Board Integration Improves Monitoring

In the fourth stage of electronic application, data produced from electronic components are transmitted to remote, off-board locations. The transfer can occur through a physical cable connection made to the component or through radio frequency (RF) transmission. RF transmission of data can be done automatically as the bus enters the transit facility or via the radio system.

The transfer of data using radio systems was greatly enhanced with the introduction of automatic vehicle location (AVL) systems. Originally developed to monitor bus location for schedule adherence and security purposes, AVL was expanded to include ridership information by integrating on-board passenger counting devices. In 1979, MTA New York City Transit (NYCT) became the first to transmit real-time information pertaining to passenger utilization and drivetrain performance (8).

The concept of using AVL and radio systems to transmit data back to the transit facility has unlimited potential. Common in aerospace and trucking applications, the technology is becoming increasingly popular in bus transit. Serving as a catalyst for off-board data transmission is the Intelligent Transportation Systems (ITS) program implemented by the Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA) and continued under TEA-21. ITS applies electronic technologies to reduce traffic congestion and make all forms of surface transportation more efficient. Additional information on ITS is provided in Chapter 6.

### Stage 5: "Super Systems" of the Future

In a future fifth stage of development, the integration of high-powered computers will accomplish tasks previously reserved for humans only, adding a new dimension to all forms of transportation. One transit example involved a bus demonstration of an automated road guidance system at Houston Metro (9). The system, which required no electronic signaling from the road itself, used video cameras to keep the bus centered in its lane and at safe distances from other vehicles. If successful, the system could permit a greater number of buses in high occupancy vehicle (HOV) lanes.

Another example of future electronic application involves the use of artificial-intelligence-based "expert systems" to help maintenance personnel diagnose equipment faults. Used in military, aerospace and other transportation sectors on a limited basis, the technology may be applied to bus transit. Serving as a mechanic's "coach," these computer programs help determine equipment failures and guide mechanics through the repair procedure by providing on-line documentation and graphics.

# OVERVIEW OF ELECTRONIC BUS COMPONENTS AND SYSTEMS

This chapter provides specific examples of second-stage electronic application where electronic controls are applied to enhance major bus components. The chapter also includes an introduction to the data networks needed to integrate them. A review of electronic fault monitoring and diagnostics is also provided.

## SUMMARY

Electronic controls have become an integral part of virtually every major bus component from engines, transmissions and brakes, to radios and destination signs to name a few. The addition of electronic controls provides certain characteristics that all major components share. In general, electronic controls:

- Replace the wiring, connectors, and relays associated with relay-logic with a single electronic control module (ECM).
- The ECM monitors operating conditions and executes commands based on pre-programmed software.
- The software can be reprogrammed to customize functions.
- Self-monitoring characteristics of the ECM identify out-of-parameter conditions, warn the operator as required, place the component in a safe operating condition to prevent damage (i.e., "limp home" mode), and record the fault in memory for future review.

In addition to improving the functionality of individual components, electronic controls can be integrated through data networks. The sharing of data between electronically controlled components allows the vehicle to perform complex functions and operate more efficiently as a result. To simplify on-board integration, the bus has been divided into three distinct levels: (1) drivetrain level, (2) electrical wiring level (i.e., multiplexing), and (3) information level (i.e., AVL, radios, fareboxes, etc.). Each level employs specific data networks to achieve integration.

Electronically controlled components also have the ability to perform self diagnostics and store performance history in memory, allowing maintenance personnel to access the data. Access to diagnostic information, typically accomplished on a component-by-component basis, can be consolidated into a single source. Early attempts to centralize on-board diagnostics were made in New York, Michigan, and Canada during the 1980s. Recent developments in electronic technology could help overcome problems associated with earlier systems.

## DRIVETRAIN COMPONENTS

### Engines

Electronically controlled diesel bus engines were introduced in 1985. Today, every bus is powered by one, and electronic controls have been optimized into smaller designs with more speed, memory, and features. In a typical application, an ECM serves as the engine's command center. It receives signals from the electronic throttle pedal, vehicle speed sensor, turbo boost sensor, air temperature sensor, fluid temperature sensors, oil pressor sensor, and other sensors. Based on this information, a "map" or built-in software program executes commands to control the delivery of fuel into the engine at precise amounts and intervals.

The ECM reacts instantaneously to changing conditions. Matching fuel delivery with specific operating conditions improves overall engine performance and enables the engine to meet stringent EPA exhaust emission regulations. Electronics has made possible several additional features including: automatic engine protection and shut-down; control of cooling fan speed based on temperature; the ability to compensate for normal engine wear; the ability to change engine parameters such as horsepower and top speed; data storage for future review; and the ability to provide diagnostic assistance to facilitate repairs.

The engine's ECM monitors faults by continually comparing inputs with prescribed conditions. When parameters are exceeded a signal can be sent to the operator, the engine can place itself in a protection mode, and diagnostic codes and operating data are stored in memory. Mechanics can access the data using a hand-held reading device or PC. Electronic controls also reduce maintenance requirements because adjustments are not required to compensate for the normal wear associated with mechanical actuators. Maintenance personnel, however, do need to acquire a new set of computer skills to operate the diagnostic equipment, and to convert diagnostic codes into repair action.

Since the engine is integrated with other components, it stores a vast amount of data such as emergency brake applications, excessive idle time, and the engine's speed and load characteristics. Much of this data, however, is available through additional software packages.

### Transmissions

The automatic transmission's ECM determines the optimum time at which to change from one gear ratio to another. Electronic signals are sent to the ECM from several devices including the throttle pedal, shift selector, and sensors that measure engine speed and torque, transmission output speed, and vehicle speed. Based on the inputs, the ECM controls the application of internal clutches to optimize shift quality. The ECM can compensate for vehicle weight, engine power, the friction coefficient of clutch discs, and changes in oil temperature and viscosity. It also uses data received from the accelerator and brake pedals to activate the retarder for optimum braking assist.

Electronic transmission controls have improved shift smoothness and consistency, and fuel economy. Similar to electronic-controlled engines, the transmission has built-in protection features and self-monitoring characteristics.

### Anti-Lock Brakes

Anti-Lock Brakes (ABS) first appeared in 1975 on buses in response to a Federal Motor Vehicle Safety Standard (FMVSS) requirement. Performance and reliability problems, however, caused the requirement to be repealed in 1978. Since then, advancements in electronic controls have improved ABS. Due to these improvements, ABS is required on all air-braked buses built as of March 1, 1998 intended for use in the United States. Additionally, hydraulically braked buses with a gross vehicle weight rating (GVWR) of 10,000 pounds or more will require ABS as of March 1, 1999.

ABS is an electronic system that monitors and controls wheel speed during braking (10). This controlled action prevents the brakes from locking, enabling the vehicle to stop with improved stability and steering control. ABS also improves tire wear, especially by preventing the "flat spots" that occur when tires remain locked for prolonged distances. The ABS system consists of wheel speed sensing equipment, an ECM, brake pressure modulator valves, and a variety of electrical harnesses, relays, switches, and lamps. Figure 2-1 shows the placement of electronic and pneumatic components in an ABS braking system.

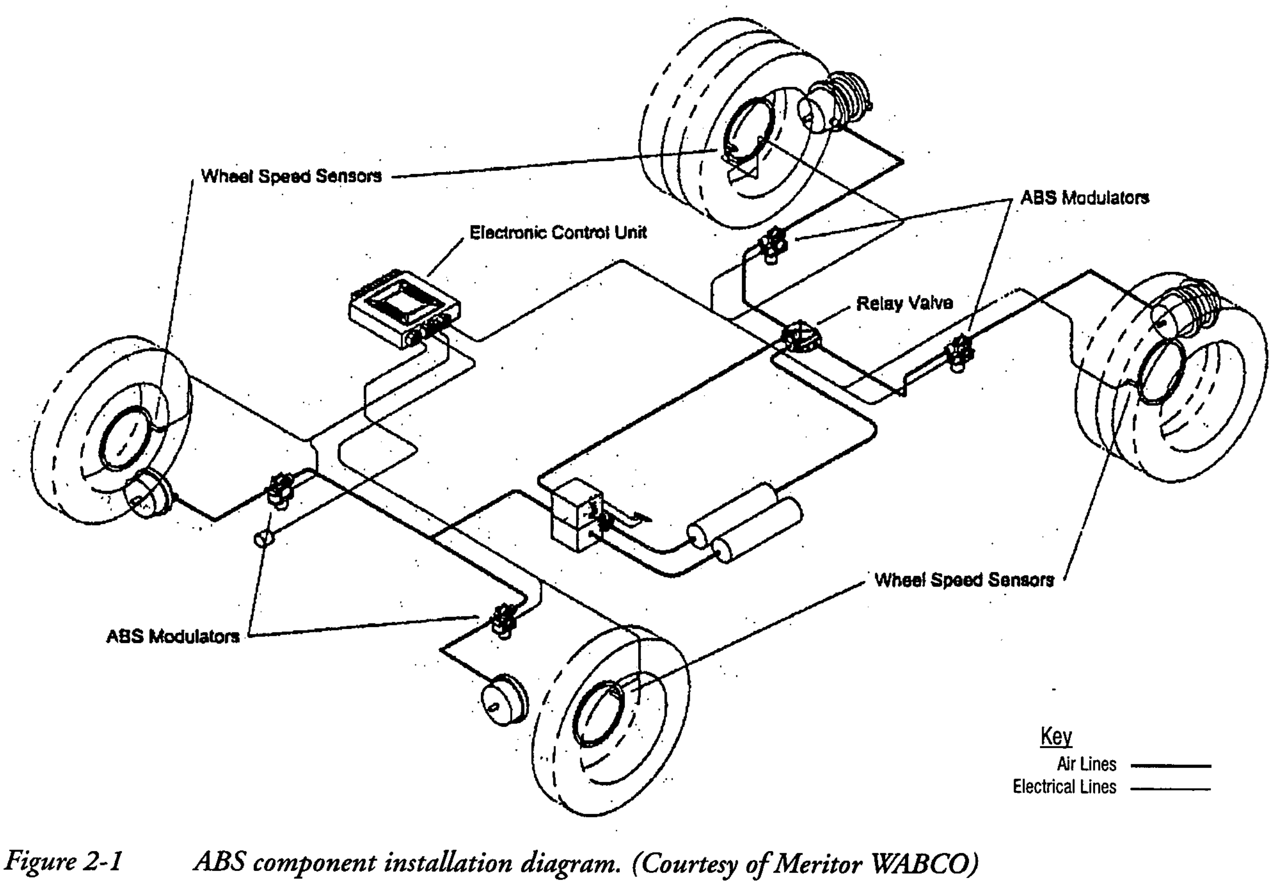


*Figure 2-1 ABS component installation diagram. (Courtesy of Meritor WABCO)*

Electronic sensors continually monitor wheel speed, sending data to the ECM. When a particular wheel locks, the ECM sends output signals to the locked wheel, momentarily releasing air brake pressure. Once the wheel begins to accelerate again, the pressure is reapplied. The process of releasing and applying air pressure occurs at a rate of about five times per second until the wheel speed approaches vehicle speed, and the vehicle finally stops. Modulating air brake pressure at a rapid rate allows the bus to stop safely without locking its wheels or loosing control.The ECM continuously checks itself and indicates any faults to the operator via a dash-mounted warning lamp. Data is also stored in memory for retrieval by maintenance personnel. Using a diagnostic port, mechanics can access data with product-specific tools or universal tools mated to a special adapter.

ABS systems can also be enhanced with additional components to provide automatic traction control (ATC), also referred to as anti spin regulation (ASR). ATC limits excessive wheel spin during acceleration by applying brake pressure automatically to the spinning wheel regardless of the operator's actions.

## BODY AND CHASSIS COMPONENTS

### Heating, Ventilation and Air Conditioning (HVAC)

Early HVAC systems consisted of simple switches to control on/off functions in either "heat" or "cool" modes. Electro-magnetic thermostats followed, which opened and closed contacts automatically when predetermined temperatures were obtained. Further enhancements, such as the ability to shut down the HVAC system under a specific set of conditions, added more wires, relays, and complexity to the relay-logic control system. When an automatic shutdown did occur, mechanics had to trace individual wires to determine the fault.

The addition of microprocessor controls has produced several HVAC benefits. Significant amounts of wiring and the number of relays needed to control comfort and safety functions have been reduced. Instead, a single ECM monitors system inputs from one location. Using pre-programmed logic, the ECM responds to specific conditions and initiates a greater range of actions. For example, if the ECM detects a failure in one temperature probe it can switch to another. If compressor cycles are too frequent, the control unit can shut it down to prevent damage and inform the operator with a warning signal. Alarm code histories saved in the ECM's memory can be accessed by service personnel to pinpoint the exact fault.

Other HVAC benefits made possible by electronics include the ability to reprogram software to customize functions, and to accommodate new equipment and features. New developments in sensor technology allow the trucking industry to monitor refrigeration temperatures via satellite. Additionally, tests are underway to permit mechanics to monitor system pressure without connecting gauges.

Integrating the HVAC control unit with other electronically controlled components provides additional benefits. In an optimized system, information such as engine speed, coolant temperature, and alternator status can be exchanged to reduce the need for duplicate sensors and wiring. Likewise, the HVAC's ECM can provide data to control auxiliary heating units and floor-level heaters.

### Doors

Compressed air has powered bus doors for over 50 years because it was readily available from the brake system. Furthermore, piping, control valves and troubleshooting were all straightforward. Pneumatic operation existed without much competition because electric motors tended to be expensive and hydraulic systems were prone to leaks.

Recently, however, several factors have combined to challenge the need for pneumatic actuation of bus doors (11):

- Interest in electrically propelled buses including battery, hybrid, and some trolley bus applications using dynamic braking and other technologies that eliminate the need for air brake and pneumatic systems.
- Interest in reducing overall bus weight;
- A decline in the cost of electric motors;
- Development of electronic systems that offer more precise control of door speed, door closing, sealing force, and other functions; and
- A desire by transit agencies to add more door control functions.

Regardless of how a bus door is powered (i.e., electrically or pneumatically), electronics has the potential to provide overall control. Based on signals received from various sensors, the ECM can manage brake and accelerator interlocks, wheelchair lift/ramp systems, stepwell lamps, overhead lights to reduce windshield glare, stop request signals, and other devices. If an out-of-parameter condition exists, the ECM can react in a prescribed manner to trigger alarms, vehicle brakes, and various interlocks to prevent unsafe conditions.

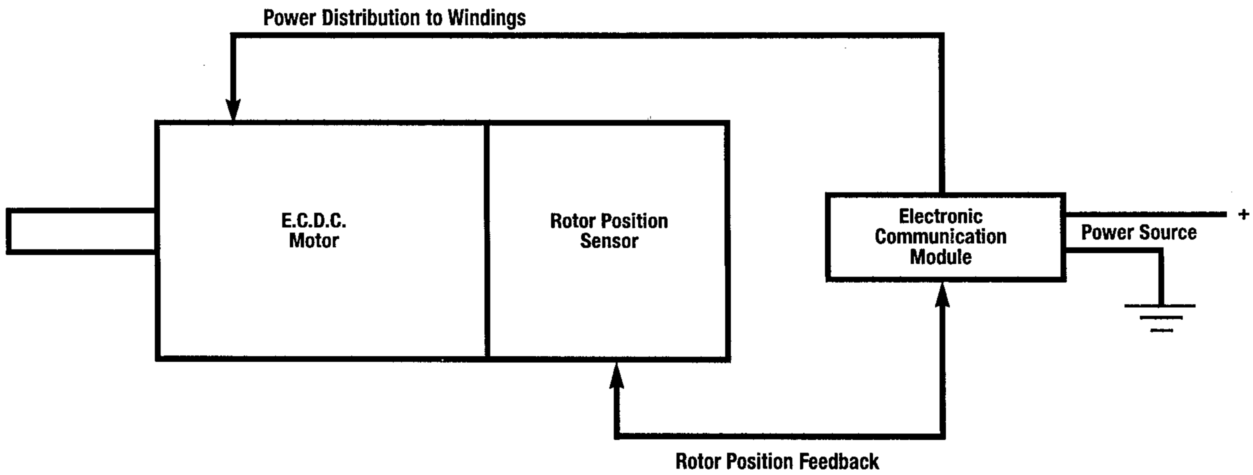


*Figure 2-2* ***Block diagram of a brushless motor.*** *(Courtesy of EG&G Rotron)*

Operating parameters can also be reprogrammed with a laptop computer to suit individual agencies.

If a sensor or subsystem component should fail, the control unit reverts to a safe condition and records the failure in memory. Fault codes displayed on the control unit indicate the failure and direct mechanics to the problem.

### Brushless DC Motors

Electronically commutated DC motors, also known as brushless motors, have been in use for over 25 years in military and aerospace applications. During the 1980s, the availability of three technologies have made brushless motors economical for automotive applications (12):

(1) High-efficiency, reliable, and low-cost power transistors, which allow high-current electronic drives to be integral with the motor.

(2) Rare-earth, permanent magnet materials, which allow higher efficiency in a smaller motor design.

(3) The hall effect device, which simplifies the identification of rotor position.

In basic terms, a brushless motor accomplishes the commutation of motor current electronically instead of using brush contacts. The system consists of a permanent magnet synchronous motor, rotor position sensor, and electronic commutation module. The rotor position sensor uses hall effect devices, which provides a digital address for each rotor position. Depending on the position, the hall effect devices activate transistors that switch current through the proper motor windings for maximum torque. As the motor rotates, a new set of windings is energized. Transistors replace the copper commutator and carbon brushes. As a result, there are no wearing components except for bearings. Figure 2-2 shows a block diagram of a brushless motor.

A brushless motor operates in an opposite manner than a brush motor. In a brush motor, permanent magnets are located within the stator (the stationary portion of the motor), while the rotating portion (rotor/armature) consists of a wound copper assembly. In a brushless motor, permanent magnets are contained in the rotor; copper windings are located in the stator.

Brushless motors can be used in a variety of low-voltage bus applications including HVAC fans, coolant circulating pumps, and electrically driven radiator cooling fans. Potential benefits include:

- Increased service life and reduced maintenance costs due to the elimination of brushes and commutators;
- The ability to limit in-rush currents on initial motor start-up, reducing impact to the power supply system;
- The ability to incorporate variable speed control; and
- Reduced heat because the external stator has a direct path for heat dissipation.

Manufacturers are currently investigating the application of microprocessor controls to brushless motors to provide further benefits. Instead of manually customizing the motor with separate components to add features (i.e., reversibility, multi speeds, adjust timing for soft start ups, etc.), changes could be made through software programming. Additionally, faults such as excessive heat and impending bearing failure could be saved in memory for fault detection.

### LED Exterior Lamps

Traditional incandescent light bulbs are composed of a thin filament suspended between electrodes. The filament used to generate the light deteriorates over time, and is prone to premature failure due to road shock and vibration (13). Used extensively for interior warning lamps, recent developments in LED (light-emitting diode) technology have produced enough light to satisfy FMVSS 108 requirements for exterior applications. Examples include identification (ID), clearance, tail, brake, and turn signal lighting.

LEDs reportedly have a life expectancy 50 times that of incandescent bulbs (14). As a solid-state device, LEDs use 98 percent of their power to produce light with only two percent dissipated as heat. As a result, LEDs should not experience the same type of degradation and failure as incandescent lamps. Instead, they experience a gradual reduction in light output over time.

In addition to extended life, LEDs have a faster response time (10 milliseconds versus 200 milliseconds for incandescent lamps) because they do not require heat to generate light. At 30 mph, the faster response rate calculates to about eight additional feet of brake light visibility for a trailing vehicle, helping to reduce rear-end collisions. Other benefits include reduced power demands, greater assurance that lamps will function, reduced in-rush current, and reduced stress on electric contacts.

## TELECOMMUNICATIONS SYSTEMS

### Radio Systems

Traditional radio systems consist of individual channels assigned to a specific group of users who listen to determine if a channel is free. Although inexpensive and simple to design and maintain, these radio systems cannot make efficient use of idle channels.

In a trunked radio system, a small number of channels are shared by a large number of users and channel selection is controlled by a central computer. When the dispatcher requests communication with a bus, the system automatically switches to an unused channel. The system also switches the called bus to the same channel automatically. There are several standards for trunked systems, without one having supremacy over another. Most radio systems are based on proprietary systems, which lock users into a particular manufacturer's equipment.

Advantages associated with trunked systems include efficient channel utilization, high reliability, and privacy (i.e., operators in other vehicles cannot hear the conversations). While appropriate for voice communication, data channels are not typically trunked because of the time needed to establish the call. Disadvantages with trunked radios include increased complexity and the need for a dedicated control channel.

The vast majority of transit agencies use analog radio communication services for both traditional and trunked systems. A few have upgraded to newer digital systems. In a digital system, the analog voice signal is encoded into a digital format and transmitted over the radio channel. At the transit agency, the digitized voice signal is converted back to its original analog electrical signal and projected over a speaker. Advantages include improved voice quality, greater immunity from noise, privacy from analog scanners, and the ability to accommodate narrower channel bands. Disadvantages include increased complexity and cost.

In addition to voice communication, digital radio permits the transmission of data as part of an integrated system. However, protocols used to support digital applications are proprietary. One such protocol involves a service called cellular digital packet data (CDPD). Similar to E-mail and cellular phones, data can be transmitted between the bus and transit agency by paying a transaction-based user fee.

A growing number of agencies are exploring new applications for transmitting data. They include sending text messages between the bus and central control, and real-time monitoring of bus location and the status of on-board equipment. Because the requirements for data transmission are high, most AVL systems dedicate a separate channel for data transmission. As a result of the increased reliance on radio communications, available frequencies are reaching the point of saturation and will require alternative solutions.

An alternative to radio overcrowding is to become a subordinate user, where permission to operate is made possible by using several frequencies on a non-interfering basis. "Spread spectrum" systems, as they are called, incorporate the use of a unique code that spreads the signal over a broader area of the channel spectrum. Since the signal is generally weaker than the noise threshold, the radio receiver uses the same unique code to recover the signal. By using different codes, many conversations could be supported within the same channel spectrum without interfering with each other.

Other alternatives to radio overcrowding include the use of excess side bands of commercial FM radio stations, and renting commercial radio services.

The Federal Communication Commission (FCC) is working to alleviate frequency spectrum overcrowding by proposing plans to "refarm" or partition existing 25 KHz mobile radio communication bands into narrower channels (15). Equipment needed to operate in narrower channels is 10 to 40 percent more expensive than existing wide-channel equipment, especially when it involves digital technology.

It first appeared that transit agencies would be forced to convert to narrower-bands. Recent provisions, however, allow agencies to use existing systems until their entire radio system is replaced. Despite the exemption, refarming is expected to impact transit. One factor involves the auctioning of certain telecommunication spectrum to the private sector. Although transit spectrum is exempt, auctioning to the "highest bidder" may limit transit attempts to obtain new spectrum at reasonable cost.

As ITS and other factors place increased demands on bus communication systems, agencies should keep informed of developments in spectrum allocation. Particular attention should also be given to new telecommunication alternatives and rapidly developing technologies. According to a study conducted by the FTA, the transit industry needs to have a strong voice in the spectrum allocation area, not only to obtain additional spectrum but to protect what it already has (16).

### Automatic Vehicle Location

Automatic Vehicle Location Systems (AVL) are computer-based tracking systems used to identify the location of buses throughout a geographical region in real time. It is based on a geographic information system (GIS), consisting of an electronic map and database that allow a user to visualize and analyze data in relationship to geographic location. For transit applications, GIS would include the underlying basemap that contains the network of municipal streets, highways, and other roads. Specific items such as bus routes, bus stops, park and ride lots, scheduling and timepoints, points of interest and other transit-specific items are then overlaid onto the basemap.

Data requirements for a GIS are extensive and generally require a database management system to manage, store, and access data. Firms that specialize in software applications build programs that merge transit-specific items with the basemap to produce AVL features such as monitoring schedule adherence and transfer points.

Location information from the bus is transmitted back to the agency and displayed on route and street maps using workstations or personal computers. Bus operators can also monitor their performance via an on-board display terminal. Information obtained from the AVL system is often combined with computer-aided dispatch (CAD) software to assist with scheduling.

AVL systems exist in approximately 30 North American agencies, with another 36 either installing or planning to install systems (8). Most of the increase has come since 1990. Expanded use of AVL systems is being driven by the following expected benefits:

- Increased dispatch and operating efficiency;
- Increased ridership due to more reliable and efficient service;
- Faster response to service interruptions and early detection of mechanical problems;
- The ability to provide additional passenger information systems such as automatic stop annunciation, off-board traveler information, etc.;
- Increased driver and passenger security through the use of silent alarms, covert microphones, and on-board surveillance cameras;
- Traffic signal preemption; and
- The ability to collect planning data more accurately than manual sampling methods.

The primary technologies used in current AVL systems consist of a combination of signposts and odometer, and global positioning system (GPS) technology. Until recently, signpost and odometer technology was the most common. It uses a series of radio beacons, typically placed along the route on telephone poles, to send a low power signal with a unique identification code. Buses receive the ID code as they pass by. When polled, they would transmit the most recent signpost ID. Using the odometer, the bus also transmits the mileage traveled since passing the signpost.

AVL systems using signpost/odometer technology have certain drawbacks. Signpost transmitters are prone to vandalism and require periodic battery replacements. Any deviation to the planned route (i.e., road construction) temporarily places the bus out of range. Additionally, route changes require the installation of new signposts.

Agencies that procured their system during the 1980s or early 1990s are the only ones continuing to use signpost technology (8). The clear choice of AVL technology today involves GPS, which uses 24 orbit-based satellites operated by the U.S. Department of Defense, and receivers placed on the roof of each bus. Coverage area includes all of North America.

In earlier systems, buses would send location information when polled from the control center. Information was then compared to a database where route and schedule adherence could be evaluated. So-called "smart buses" contain a route/schedule data base in the on-board vehicle logic unit (VLU). Since the bus can calculate its own position and determine schedule adherence, it only reports to central control when running outside the predefined schedule limits. As a result, a separate polling data channel is not required. Additionally, the reduced need for data transfer allows more buses to share the same data channel.

GPS signals can be degraded when vehicles are positioned between tall buildings and dense foliage, or when traveling underground. Another impediment to accuracy involves Selective Availability (SA), which is present on all commercial GPS receivers. SA is a technique used to intentionally degrade the accuracy of commercial GPS receivers to protect U.S. military interests in times of crisis. With SA enabled GPS's accuracy is only about 300 feet (91 meters), compared to 50 feet (15 meters) when SA is not operating. Other factors contributing to the inaccuracy of GPS include satellite and receiver errors, and atmospheric conditions.

As a result of the conditions described above, GPS typically requires additional technologies to help improve location accuracy. One method involves the use of Differential GPS (DGPS). In simple terms, DGPS uses a fixed receiver mounted in a known location to confirm the accuracy of GPS signaling. If the location of a known structure as reported by GPS differs from the actual location, the differential or "correction factor" is applied to improve the accuracy of bus location. The correction factor can be based on a transit agency maintaining its own fixed site, through U.S. Coast Guard maintained DGPS sites, or from companies that transmit differential correction data using FM radio frequencies. However, if the GPS signal is blocked, differential GPS is of no benefit.

Another method to improve the accuracy of GPS when satellites become obstructed involves the use of an odometer, which calculates position based on the distance traveled since the last signal was received. Signposts are also used in specific locations to supplement GPS in areas of poor reception.

Dead Reckoning is a technique that can be used as a stand-alone method of determining vehicle location or to supplement an existing GPS system. It measures the vehicle's acceleration and direction. Using a known starting point as a reference, the dead reckoning unit uses odometer and compass inputs to determine vehicle position from the starting point. Fiber optic gyroscopes can also be used to assist the dead reckoning process.

If dead reckoning is used as a stand-alone system, there must be an external way of periodically "registering" the vehicle at certain locations. This can be accomplished through signposts, or by requiring the operator to make a manual input at selected bus stops.

## AUTOMATIC PASSENGER COUNTERS

First used in the 1970s, automatic passenger counters (APC) record passenger boardings using different technologies. Mechanical systems react to the pressure of a passenger's foot as he/she steps on a treadle mat; electronic systems use infrared light beams. As a passenger boards or leaves the bus, two infrared beams placed across the passenger's path are broken in a particular sequence to register the activity.

To link passenger activity with specific route stops, APC systems are also used in conjunction with AVL systems. APC can also be installed as a stand-alone system using any one of the vehicle-positioning options mentioned above. Transmitting APC data depends on how quickly an agency plans to use the data. The two most common options include real-time (at least once every 10 seconds) and off-line (delayed).

If real-time data is required for dispatching purposes, the APC unit must be integrated with the AVL and radio systems. Agencies, however, need to consider the cost of fitting each bus with APC equipment and the extra radio capacity required to transmit the data in real time.

A more cost-effective alternative is to rotate a limited number of APC-equipped buses periodically on all routes. Using this approach, passenger counting data could be downloaded using several methods: a physical plug-in cable connection made between the APC and a laptop computer; a short-distance radio frequency (RF) link established between the APC and the bus; or a disk taken from the APC to a computer.

## ON-BOARD PASSENGER INFORMATION

As one of its provisions, the Americans with Disabilities Act (ADA) requires buses over 22 feet in length to have a system that announces route stops and provides other passenger information (17). To satisfy these requirements, some agencies use electronic systems that automatically trigger voice announcements using pre-recorded messages. Complementing the audio system are interior signs for the hearing impaired.

The method used to trigger information depends on whether the agency has an AVL system. Agencies with AVL typically integrate in-vehicle passenger information systems with existing location technology to trigger announcements. Using GPS signals, the control unit automatically determines adherence to the bus route and triggers next-stop information. The system can also detect when a bus goes off route and remains silent. When back on route the system picks up where it left off, announcing the next scheduled stop without driver intervention.

Agencies without AVL can apply next-stop announcement systems in one of two ways. In a manually-triggered approach, the operator depresses a key pad button or foot switch to activate the interior destination sign and/or pre-recorded voice announcement. Another approach is to specify GPS as a stand-alone triggering system for announcements. The stand-alone system could be expanded at a later date into a full AVL system.

## FARE PAYMENT SYSTEMS

### Background

Fare payment technology has come a long way from the mechanical "drop box." As fares approached one dollar in the late 1970s, agencies turned to electronic registering fareboxes to process cash, tickets and tokens; and to record trip-related data such as zone and passenger type. The first electronic fareboxes were troublesome due to poor design and lack of electronically skilled maintenance personnel. Today, reliability has improved and electronics has expanded the role of fare collection to include several new technologies (18, 19, 20).

The application of electronics has the potential of offering agencies a variety of fare objectives which may include:

- A pricing structure based on distance traveled, time of day, and type of passenger;
- The reduction and eventual elimination of cash fares to improve security and lower handling costs;
- Automation of the settlement process with financial institutions (i.e., banks) to lower costs; and
- The creation of multi-modal networks that are seamless to the passenger, but operationally and organizationally sound for the agencies involved.

This review focuses on electronic developments in two areas: fare media such as magnetic tickets and smart cards; and fareboxes that process the media.

### Non-Cash Fare Media

Although cash is the most common means of paying fares, agencies are investigating non-cash media to circumvent cost and security issues associated with handling cash. Non-cash media include a type of ticket or card that contains printed information and/or stored information. Paper tickets typically include printed information only, while magnetic tickets and smart cards use electronic technology to store information. Potential advantages offered by electronic media include:

- A higher degree of revenue control;
- Increased information pertaining to ridership usage and patterns;
- Increased flexibility in establishing fare options and levels; and
- Regional fare integration that allows riders from different systems to use a single ticket while retaining their individual fare structures.

A major drawback involves the cost of the media and the fare collection equipment needed to process it. Other potential drawbacks include forgery of tickets and the potential for system integration problems that can occur when trying to apply electronic media to a variety of fare collection equipment.

#### *Magnetic Tickets*

Magnetic-stripe tickets can be used for a variety of payment options including single-ride, multi-ride, period pass, or stored value. They can be used in buses when the farebox is equipped with ticket readers and processing units. If an agency uses magnetic tickets for its rail system, magnetic-ticket readers in buses allow passengers to use the same fare media. Less than 10 percent of bus systems use magnetic on-board fare collection technology (19).

#### *Smart Cards*

Popular in Europe, smart cards are also attracting attention in the U.S. A smart card is a credit-card-size integrated circuit (IC) with built-in logic capabilities. The term is also used to describe "memory cards" that store information but do not contain internal processors. Smart cards store large amounts of data, offer increased security, and have a longer life cycle compared to magnetic-stripe cards. They can also maintain different accounts within their memory for different clients or agencies (i.e., bank and department store transactions), and are easy to add value to. Smart cards typically fall into two categories:

1) Contact Cards that require a physical contact between the card and reading device; and
2) Proximity Cards that transfer data without making physical contact with the reader.

### Fareboxes

Electronically registering fareboxes are commonplace in buses today. In a typical scenario, the operator uses a keypad to indicate a fare category for a boarding passenger, and to enter identifiers such as operator ID and route number. As each passenger boards, information is captured regarding the fare category, payment media and the amount of cash received. Improved security measures include electronic tracking of revenue and data as the cashbox and vault are moved throughout the property.

Technology developments include the fitting of swipe readers to accept magnetic tickets, and ticket processing units (TPUs). TPUs issue paper transfers, or issue and accept magnetically encoded tickets. Tickets obtained from a vending machine, or the TPU of another bus, are processed onboard by deducting value or a ride. A display informs passengers of the remaining value/rides.

Another major development involves the use of transactional databases. In a traditional summary database, information from each transaction is not saved but is used to update cumulative records (i.e., number of boardings in each fare category, fare revenue, etc.). The summation continues until the operator enters a change (i.e., route, direction, run or change of operator). Transactional data offers greater flexibility because a record is created and stored for each transaction including the fare category, payment media, operator route, and run number. A time stamp is also included with each transaction.

The detailed accounting of each transaction allows agencies to obtain more meaningful statistics including the tracking of promotional based fares, fare media issued by other agencies for revenue allocation purposes, and linked-trip patterns (21).

The next stage of farebox development involves integration with other on-board electronic equipment such as AVL, passenger counters, destination signs, and others. For example, if transactional records were also stamped with the vehicle location, passenger boardings and related fare data could be segmented by each stop. Integration with other devices also permits the use of a single keypad to reduce the need for redundant hardware and multiple sign-ons by the operator. Integration of the various components requires them to be compatible with one another, which may be difficult if procured independently at different times.

## ELECTRICAL MULTIPLEXING/DATA NETWORKS

Multiplexing is a term used to describe a broad range of procedures that involve the integration of electronic components and systems. In simple terms, multiplexing can be described as a way of transmitting several lines of communication simultaneously on the same network (22). The telephone system serves as a good analogy. Although telephones are all connected through a worldwide network, the network is accomplished by sharing communication lines — not by running separate wires to every possible combination of phones.

As the transit bus developed since the 1970s, two issues needed to be addressed:

(1) The growing number of devices requiring battery power increased the size and complexity of the relay-logic-based control system; and
(2) Electronically controlled components with the ability to exchange data required a method to "communicate" with one another.

Electrical system multiplexing was applied to buses as a way of streamlining the electrical system. Data networks, developed by the Society of Automotive Engineers (SAE), were applied to integrate electronically controlled components. First applied to the integration of drivetrain components, SAE data networks were expanded to include other equipment as well.

### Electrical System Multiplexing

To resolve the problem of using individual point-to-point wires and relays to control each component, bus manufacturers have replaced traditional wiring systems with electrical system multiplexing. In a "multiplexed" system, a microprocessor uses software and its own two-way data network to control power switching to electrical devices. Instead of running separate power and ground wires throughout the bus, data signals are sent to modules located at strategic locations. The localized modules, which contain battery power and ground, distribute electrical current as directed by the system's microprocessor. Controlling the switching of power from specific locations generates savings in space, weight, design time, installation, troubleshooting, and general maintenance (23). Detailed information on electrical system multiplexing is provided in Chapter 4.

### Data Networks

To address the transfer of data between electronically controlled components in heavy-duty vehicles, SAE developed serial data communication standards. The process of data transfer is identified by many names. Some of the more common terms include: data networks, data link, data bus, or simply bus. To avoid confusion with transit "bus," this study will use "data network" to denote the exchange of data between electronic components and systems.

A data network uses a process by which information generated by one device is converted from parallel form to serial form so it can be transported to another device. Once received, the information is converted back to parallel form. The purpose of converting information is to reduce the hardware and costs associated with connectors and cables.

Data networks ensure that all devices connected to it interpret data in the same manner. One example is vehicle speed, an important piece of information that can be used by a number of components. However, before a single speed sensor can provide identical information to all components, the format of that information must be specified. Data networks are merely the specifications used to define how information is transferred from one device to another. Additional information on data networks is provided in Chapter 5.

### The Three Levels of Data Networks

A popular misconception concerning electronic integration is that a "universal" system is used to exchange data throughout the bus from engines, transmissions, and anti-lock brakes, to AVL, destination signs, fareboxes, and the wiring system itself. While this is a lofty goal and may someday be the case, the use of a single data network does not exist in bus applications for one primary reason. While electronic bus systems were developing, there was no single network with the capability of handling data interactions between all electronic components. Hence, separate data networks were applied to specific bus systems as they developed.

To simplify our explanation, the application of data networks is organized in three bus levels to reflect the development process. This three-tier segmentation is consistent with the development approach being pursued in both the U.S. and Europe. Although different terms are used to identify the three levels, this study will refer to them as the Drivetrain Level, Electrical Level, and Information Level. Figure 2-3 shows each of the three levels superimposed on a bus.

It is important to note that Drivetrain and Electrical Level integration is accomplished by the bus manufacturer and delivered to the transit agency as a complete operating system. Information Level integration, however, is typically accomplished by system integrators who tend to install equipment after the bus has been assembled.

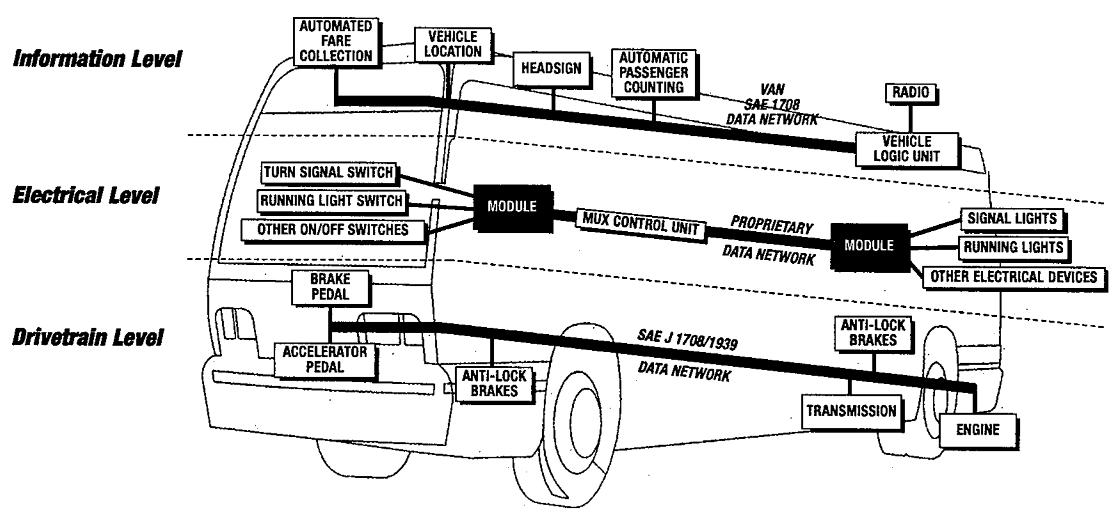


*Figure 2-3* *The three levels of electronic integration developed around separate data networks.*

*Drivetrain Level* - This level includes components critical to vehicle driveability such as the engine, transmission, retarder, anti-lock brakes (ABS), and traction control systems. Due to their critical nature, bus manufacturers apply data networks developed by SAE exclusively for drivetrain components. The use of dedicated networks prevents critical drivetrain-related components from being impacted by other bus functions.

*Electrical Level* - This level represents the electrical system of the bus that controls power throughout the vehicle. In a traditional system, individual wires provide power and ground to control electrical devices through a series of relays, known as relay logic. To overcome this complexity, virtually every transit bus manufactured today offers a streamlined wiring system that many generically refer to as "multiplexing."

Multiplex electrical systems are typically used to control relatively simple 12- and 24-volt functions. Examples include turning electrical devices on/off, serving as a signal/emergency flasher, and initiating time delays.

*Information Level* - Components and systems in this level include AVL, destination signs, fare collection, automatic annunciators, camera security, APC, and other components. This area of the bus is receiving particular attention because of its ability to furnish information needed to provide a higher level of service efficiency to passengers. In the U.S., efforts to integrate components in this level center around the "Vehicle Area Network" or VAN.

Integration at this level can range from combining a few basic functions to consolidating virtually every on-board device. Combining of functions at this level is typically carried out by system integrators, companies that specialize in AVL and communication technologies. At the heart of the system is a vehicle logic unit (VLU) integrated with the radio. As a microprocessor, the VLU has the ability to monitor all activity on the network, store data for future retrieval, or transmit data to the agency for real-time monitoring.

VAN has adopted the SAE J1708 data network as the foundation for this level, while the Europeans are generally using the Controller Area Network (CAN) developed by Bosch. (France is proposing a separate, WorldFIP protocol). Each network provides a standard "language" that electronic components can use to "communicate" with one another. Without it, the integration of electronic components would not be possible.

### Gateways Combine Data Networks

Although the bus has been divided into three levels for the purpose of explaining electronic integration, the levels are not autonomous. Electronic modules, called "gateways", allow interaction between components operating on different data networks. For example, data from the Drivetrain Level can be sent to the Information Level AVL system to report critical engine malfunctions.

## ON-BOARD FAULT MONITORING AND DIAGNOSTICS

As noted earlier, microcontrollers (i.e., ECMs) found in each major component also have the ability to perform self-diagnostic tests. The ability to perform these tests, record the results in memory, and communicate data depends on the capabilities of each component. Drivetrain components typically have the most advanced diagnostic capabilities. Depending on the fault, a drivetrain component can alert the operator and make certain information available to the other drivetrain components. According to instructions built into each component's software program, actions are taken to protect against damage. Depending on the fault, the engine may limit bus speed or shut itself down; the transmission may restrict itself to certain gear ranges.

Fault information can be communicated to maintenance personnel in several ways depending on the component. Those with less critical functions tend to use LED lamps that flash in a particular sequence to indicate faults. In other basic systems, fault codes are displayed directly on the control unit itself. More advanced components, such as those found in the Drivetrain and Information Levels, have greater data storage and diagnostic capabilities. In addition to triggering a warning signal or alarm, the historical data stored within them allows properly trained mechanics to perform a more detailed analysis. The analysis could be in response to a specific warning alarm, or as a review of all operating conditions to identify impending failures.

To access data for further analysis, mechanics use a hand-held reading device or PC. Components such as engines, transmissions, ABS, air conditioning, and other systems have dedicated ports or plug connectors that mate with specific diagnostic tools. The engine and transmission also have plug connectors in the operator's area to perform driveability tests. Although the plug connectors have been standardized in some applications, each product generally requires its own diagnostic tool to extract data. This component-by-

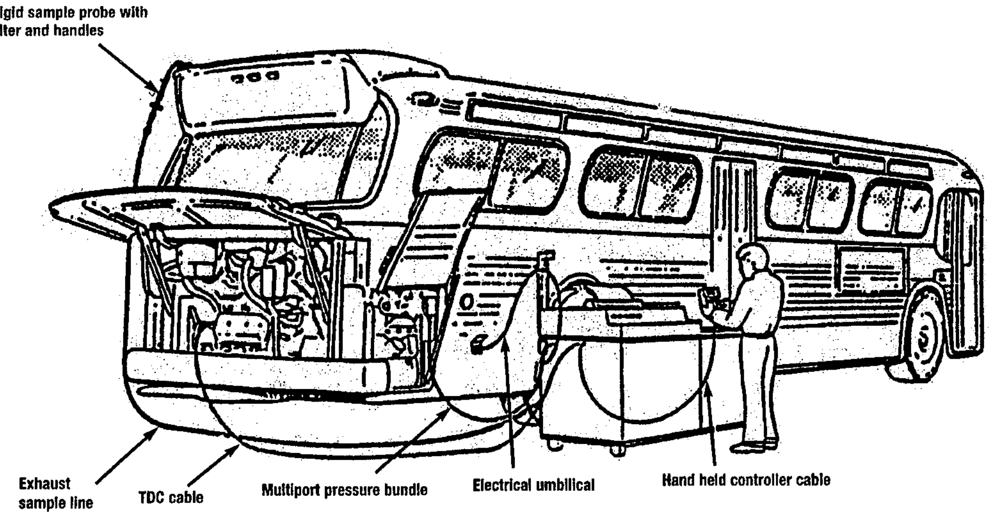


*Figure 2-4* *Technician performing a scheduled maintenance inspection with assistance from the ABDS Maintenance Area Unit.*

component approach to diagnosing faults is the most common method used in bus transit today.

An alternative method involves collecting performance data from several components/systems and directing it to one on-board location for dissemination. Systems integrators, AVL suppliers, and suppliers of electronic data recorders are typically involved in the process of consolidating vehicle performance data. The systems collect and store data by interfacing with existing data links or using separate sensors.

Data are typically stored in an on-board computer or the VLU. Once stored, they can be downloaded for further evaluation, transmitted to radio frequency (RF) transceivers on the service lane, or sent to central maintenance via the radio/AVL system in real-time. Typically monitored conditions include engine oil pressure, engine coolant temperature, air brake pressure and other conditions desired by the agency.

The process to develop a centralized on-board performance monitoring and diagnostic system has been undertaken on an agency-by-agency basis for several years. While some have made substantial progress, the bus industry as a whole has not adopted a universal approach to on-board diagnostics. Doing so will require a coordinated effort by transit agencies, component suppliers, and bus manufacturers.

## ABDS

The first known organized attempt to centralize on-board diagnostic functions began in the 1980s when the Federal Transit Administration (then called the Urban Mass Transportation Administration) funded demonstrations of the Automated Bus Diagnostic System (ABDS) in New York City, Syracuse, (NY) and Flint (MI). ABDS was intended to reduce maintenance costs and road calls by providing a means of early fault detection and computer assisted diagnosis (24).

ABDS was comprised of On-Board Bus Sensors, a Fuel Island Unit, and a Maintenance Area Unit. On-Board Sensors collected data from several locations to a single microprocessor. A small door located behind the rear wheelhousing provided access to a plug connector, allowing the bus to communicate with the Fuel Island Unit and the Maintenance Area Unit. The Fuel Island Unit performed daily checks in the service lane, while the Maintenance Area Unit performed more extensive tests during scheduled service intervals. Mechanics were guided through the procedure with a hand-held controller, and provided with a complete post-test report. Figure 2-4 shows the ABDS diagnostic system being used during a scheduled service inspection.

ABDS was developed and tested for nearly ten years until funding and manufacturer support eventually ended. Sensors tended to be unreliable, triggering false alarms. Despite the technical problems and lack of support, the MTA in Flint Michigan continued to operate the ABDS system on a limited basis with favorable results (25). FTA's ABDS program was clearly ahead of its time. The self-diagnostic capabilities of today's electronic components combined with data networks could make a similar program useful to bus maintenance.

### 1988 Canadian On-Board Diagnostic Study

In 1988, a study concerning on-board diagnostics was sponsored by Transport Canada, the Transportation Development Center (TDC), and the Ontario Ministry of Ontario (26). Over 10 years old now, the study recommended an approach that could be applied today, especially with the development of more sophisticated on-board data recorders. The Canadian study recommended a personal computer-based diagnostic system that would:

- Use the capabilities of existing on-board electronics found in engines and transmissions;
- Use data communication protocols developed by the American Trucking Association (ATA) and SAE;
- Be expandable to include other subsystem diagnostics when available; and
- Incorporate expert type assistance in isolating faults.

The study emphasized that transportation electronics will be heavily dependent on software development and urged government officials to cooperate and support these technologies.

# ELECTRONIC DEVELOPMENTS IN OTHER TRANSPORTATION SECTORS

Before moving on to describe the use of multiplexing and data networks in buses, this chapter reviews the application of on-board electronics to automobiles, heavy-duty trucks, and rail transit.

## SUMMARY

Transit buses are one of the many modes of surface transportation applying on-board electronics to improve safety and operating efficiency. As the largest transportation sector, the automobile plays a leading role. More closely related is the heavy-duty truck, from which buses derive many of their components. An obvious difference between transit buses and their siblings is that automobile and truck manufacturers are more actively involved with the integration of Information Level components.

For example, heavy-duty trucks are delivered to fleets with vehicle location, radio, radar collision avoidance and other systems pre-engineered into the truck. With transit buses, Information Level integration is typically performed as retrofits by systems integrators. Another major difference is that auto and trucking industries have standardized data networks to facilitate the integration, while efforts to do the same by bus transit are still ongoing.

In addition to the many electronic features pertaining to safety and comfort, all new cars and light trucks feature a standardized on-board diagnostic system to detect emissions-related faults. The requirement, based on SAE data networks, allows vehicles built by multiple automakers to be diagnosed at any repair facility using standard tools and procedures.

Operated as independent companies in a highly competitive market, the heavy-duty trucking industry has a long-standing tradition of using electronic technology. Monitoring both the operator and vehicle is essential to maximizing efficiency and profits. Like the auto industry, heavy-duty trucking has developed a universal environment for integrating on-board electronics around standard SAE data networks. The effort was organized by the American Trucking Association (ATA) working in close cooperation with the SAE, suppliers, and fleet operators. Early efforts focused on electronic drivetrain integration, which quickly expanded to include Information Level components. The development of SAE J1708 and J1939 was a result of the collaborative effort to integrate heavy-duty truck electronics.

Trucking companies can choose from a variety of Information Level electronics. Included are global positioning technology and radio communication systems to monitor several vehicle and operator conditions such as excessive idle time, excessive vehicle and engine speed, and cargo refrigeration temperatures. The systems are also used to track and schedule the movement of freight as it travels throughout the country. Each major component is compatible with SAE data networks, allowing fleet operators to choose products from several vendors.

Like its bus counterpart, rail transit is beginning to address the interfacing needs of on-board electronic technology. To fulfil the rail transit industry's desire to contain costs, the Transit Cooperative Research Program (TCRP) is engaged in research that seeks to develop standard interfaces between rail systems and subsystems. An Institute of Electrical and Electronic Engineers (IEEE) Committee is working to develop electronic interface standards in specific areas such as train monitoring, diagnostics, communication protocols, environmental conditions for electronic equipment, and passenger information systems.

## AUTOMOBILES

### Background

With an annual North American production of over 15 million units, the automobile is clearly the on-highway leader in applying advanced electronics. Due in large part to electronics, today's automobile requires less maintenance, is more reliable, and lasts longer than those built 20 years ago. Electronic ignitions, introduced during the 1970s, represented the first high-volume electronic application followed by electronic fuel injection, cruise control, and intermittent wipers. In the 1980s, electronic advancements included full powertrain control, ABS, traction control, seat memory, crash sensors, remote keyless entry, and other features. During the 1990s, multiplexing, on-board diagnostic systems, navigation systems, and integrated controls were introduced (27).

Analysts project that the automotive electronics market will reach $80 billion worldwide by 2003, more than double the worldwide total of $37 billion in 1993. By 2005, electronic components will equal 20 percent of a vehicle's value, a 5 percent increase from 1996 costs.

### Standardized On-Board Diagnostics

The vast majority of automobile electronics enhances passenger comfort, convenience, and safety. An interesting aspect, however, involves the universal application of on-board diagnostics to detect emissions-related faults. Beginning with the 1994 model year, all cars and light trucks are required to have such a system. The requirement stems from a cooperative effort between the Society of Automotive Engineers (SAE), the EPA, and the California Air Resources Board (CARB) (28).

In 1988, CARB required that all cars and light trucks sold in California be equipped with an on-board diagnostic (OBD) system. It provided drivers with an early warning of deteriorating emissions characteristics, and mechanics with basic diagnostic information to correct the problem. Simultaneously, SAE adopted a "Vision of the Future" to address automaker and repair industry concerns over the increasingly complex nature of vehicle electronics. This vision, which remains virtually unchanged today, consists of the following (28):

- All vehicles will use a standard set of diagnostic test modes that can be executed over a standard communication data network;
- A standard connector in a standard location will be fitted to all vehicles;
- Diagnostic tools will be able to extract a minimum set of standardized diagnostic test modes and test information from all vehicles; and
- A system will be in place to allow standard electronic access of all electrical/electronic diagnostic service information.

SAE's vision produced a series of recommended practices to provide the uniformity needed to apply diagnostics across a broad range of manufacturers and vehicles.

Using SAE's recommended practices as a framework, CARB and EPA concurrently issued new on-board diagnostic requirements, known as OBD-II, for 1994 and later model year light and medium duty vehicles (29, 30). Under these regulations, vehicle manufacturers must provide diagnostic information using standardized terminology, fault codes and plug connectors.

Table 3-1 lists the SAE recommended practices mandated by EPA and CARB regulations. The Table also lists the recommended practices that the auto industry has adopted as voluntary in an effort to achieve greater commonality.

| | Mandated | Voluntary |
|---|---|---|
| *On-Board* | J1850 Communication Protocol<br>J1962 Diagnostic Connector<br>J1979 Diagnostic Test Modes<br>J2012 Diagnostic Trouble Codes | J2178 Class B Non- Diagnostic Messages<br>J2186 Tamper Resistance (CARB)<br>J2190 Enhanced Test Modes<br>J1699 J1850 Verification |
| *Off-Board* | J1930 Terms and Definitions<br>J1978 Diagnostic Scan Tool<br>J2205 Expanded Scan Tool Protocol | J2201 Scan Tool Interface<br>J2008 Service Info |

*Table 3-1* ***Mandated and voluntary SAE practices for on-board diagnostics applicable to passenger automobiles and light trucks.***

### Data Networks

For the most part, American automakers have settled on SAE J1850 as the data network for mandated OBD-II diagnostics and all electronic interfacing needs including non-emissions related diagnostics and component integration. However, each of the Big 3 automakers (GM, Ford, and Chrysler) along with European and Japanese automakers, use their own variation of the J1850 network to satisfy proprietary needs. As a result, electronic component suppliers must modify each product to accommodate each of the J1850 variants.

In Europe, automakers have typically settled on the Controller Area Network (CAN) developed and licensed by Bosch. Because of standardization to CAN, European automakers run a separate J1850 data network to satisfy OBD-II requirements for U.S.-marketed vehicles.

## Future Developments

Future automotive electronic developments focus on ITS-related functions such as distance-sensitive cruise control, lane departure warning, and fully automated hands-free driving. Distance-sensitive cruise control monitors the distance of vehicles ahead and automatically adjusts the car's speed to maintain a safe gap. Lane departure warning systems respond to driver fatigue by activating a warning buzzer if a car begins to drift out of its established lane. The system can also warn the driver when making an intentional lane change if other vehicles are in the driver's "blind spot."

Fully automated hands-free driving, although a long way from being perfected, has been demonstrated. It requires several technologies including magnetic markers imbedded into highway lanes, on-board lateral and longitudinal control, obstacle detection and avoidance, collision and lane-departure warning, and vehicle-to-vehicle communication. The electronics would allow vehicles to ride on invisible tracks made by magnetic markers imbedded into the pavement. Another approach consists of vision-based systems that use on-board cameras to detect obstacles ahead and to follow painted lane markings.

# HEAVY-DUTY TRUCKS

## Background

Production of Class 8 heavy-duty trucks in the U.S. and Canada totals about 200,000 units annually, considerably more than the annual production of about 3,000 units for standard-size transit buses. The trucking industry has a long-standing tradition of using electronic technology to monitor both operator and vehicle performance. Electronic journey recorders called "tachographs" were first used to record vehicle movements in speed, time, and distance traveled.

As a deregulated commercial enterprize, the trucking industry is very competitive and overall cost of operation is essential to financial success. Because of this, on-board electronic systems are viewed as a way to operate more efficiently and maximize profits.

## On-Board Electronic Integration

All major on-board truck components — engine, transmission, anti-lock brakes, radio communication, vehicle location, data recorder computer, air conditioning, air suspension, dashboard, and radar collision avoidance — are integrated by standard SAE data networks. Integration around these networks provides manufacturers with a level of standardization, keeping them from redesigning each truck to satisfy customer requirements for unique combinations of components.

Development of a universal environment for on-board integration was made possible by the Truck Maintenance Council (TMC) of the American Trucking Association (ATA) working in close cooperation with the SAE. Data networks such as J1708/J1587 and J1939, first developed for both truck and bus drivetrain applications, was a direct result of efforts taken by the ATA and SAE. Further work resulted in standards for a common on-board diagnostic plug connector and diagnostic tool requirements.

Integrated on the network is a data recorder, a microprocessor device similar to the VLU used in transit. It records several vehicle and driver functions including engine speed, vehicle speed, oil pressure, coolant temperature, and refrigeration temperatures. Depending on the application, conditions are stored for review at a later date or sent in real time to a trucking facility.

Additional features include monitoring of the truck's geographical position (i.e., AVL), allowing customers to be informed of freight locations. Geographical positioning also permits trucking companies to match trucks in the field with new freight business. According to one source, about 15,000 trucks have the ability to monitor location and other operating conditions in real time (31). In one case where a truck was stolen, the on-board computer recognized that the operator had not logged on and the vehicle was off its scheduled route. It then used its radio system to notify the police, reporting the truck's exact location to help apprehend the thief (32).

On-board data collection and storage systems for trucks also have provisions that allow the operator to enter additional information such as fuel purchases and other expenses manually. Again, all on-board electronic devices are integrated through common SAE data network. This allows fleet customers to specify components from several manufacturers knowing they will operate on the same network.

A typical new heavy-duty truck incorporates a SAE J1708/J1587 network for Information Level integration, and a J1939 network for Drivetrain Level integration. The trucking industry is working to use either SAE J1708 or the J1939 data network to control on/off type power (i.e., multiplexing) throughout the vehicle.

### On-Board Diagnostics

The trucking industry, primarily through the efforts of the TMC, has made substantial progress incorporating on-board diagnostics as part of its overall electronic integration process. The first generation of diagnostics is included in the SAE J1708/1587 protocol, which defines the (33):

- Source of the fault (e.g., engine);
- Failure mode (e.g., open electrical circuit);
- Least repairable component (e.g., the engine oil pressure circuit); and
- Number of times the fault had occurred.

The next generation of on-board diagnostics, as defined by SAE J1939, allows for additional failure modes (up to 32), and least-repairable component identifications (about 500,000).

Bus transit makes use of the same procedures developed by the SAE and TMC to access on-board diagnostic data. The extent to which the data are utilized depends on the capabilities of each agency. According to one authority on vehicle-based electronics, transit lags behind trucking in its ability to make use of the diagnostic data available through existing electronic components (34).

## RAIL TRANSIT

### Background

Similar to its bus counterpart, rail transit is in a state of transition as it begins to incorporate new on-board electronic technology and address the interfacing needs of this new technology. The first major production of advanced technology heavy rail cars went into service on Boston's Red Line in 1994 (35). Three-phase AC traction motors use microprocessor controls for both propulsion and regenerative braking. Conventional air brakes also incorporate microprocessors to take full advantage of regenerative braking.

Boston's Red Line cars include a comprehensive on-board diagnostic system that can be monitored from a screen at each cab and stored in memory for downloading to a portable computer. Propulsion and braking system diagnostics include a menu-driven software package that allows mechanics to identify a failure based on the lowest replaceable unit level. HVAC and door systems are also microprocessor controlled and linked to the on-board monitoring system.

Future applications of advanced electronics include state-of-the-art rail cars under development for MTA New York City Transit (NYCT). The first deliveries of NYCT's "R-142" stainless steel rail cars is expected to begin in the summer of 1999. Advanced on-board electronic features will include microprocessor-controlled regenerative braking, communications-based train controls, trainline multiplexing, a central diagnostic system, digital communication system, and electronic signs and next-stop announcements for passengers (36). Amtrak's high speed cars planned for the Northeast Corridor will also represent state-of-the-art applications of on-board electronics.

### Standards Being Developed

Rail transit has recognized that a lack of standardization regarding the application of new technology can contribute to increased costs for rolling stock and spare parts needed to support unique fleets. To help fulfil the rail transit industry's goal of developing standard specifications for new railcars, the TCRP is engaged in research (Project G-4) that uses a formal consensus building approach to develop these standards (37). The standards development process is focusing on the interfaces between specific systems and subsystems, and not the systems and subsystems themselves.

Through TCRP Project G-4, an Institute of Electrical and Electronic Engineers (IEEE) Rail Transit Vehicle Interface Standards Committee has been formed to develop various standards. The IEEE committee has formed individual working groups to develop interface standards in eleven areas:

(1) Communications based train control;
(2) Rail vehicle monitoring and diagnostic systems;
(3) Communication protocols aboard trains;
(4) Environmental conditions for electronic equipment;
(5) Safety considerations for software;
(6) Functioning of interfaces among propulsion, friction brake, and train-borne master control;
(7) Passenger train auxiliary power systems;
(8) Passenger information systems;
(9) Transit Communication Interface Profiles (TCIP) for rail transit;
(10) Rail transit vehicle battery physical interface; and
(11) Motor Control Standards.

The working groups are in the process of developing standards for each area identified. A summary of key activities is provided below.

*Communication Protocols*

Rail cars are manufactured using pre-assembled modules that perform many different functions. Data networks allow these modules to communicate with one another for purposes such as traction control, diagnostics, and passenger information.

The rail industry does not have a preferred communication standard, allowing train builders to use their own communication approaches. The goal of this working group is to specify the protocols for both inter-car and intra-car data communications. The protocols will permit a variety of suppliers performing different on-board functions to share a common communication method.

According to the TCRP project, the creation of a standard data communication protocol has the potential to save over $56 million annually. This estimate, which is based on an 80 percent chance of success, includes the potential savings from reduced electrical hardware, complexity, and maintenance.

The process to develop a communication standard builds on two existing protocols: LonWorks and the Train Communications Network (TCN). LonWorks, developed by Echelon, is a general purpose control networking protocol used to connect components and systems within one rail car or train set. TCN was originally developed in Europe to allow compatibility between trains operating in different countries.

*On-Board Diagnostics*

As in bus transit, there are no defined rail standards to monitor, collect and present operating status and fault information. Each new order of rail cars, along with those slated for overhauls, requires an engineering effort by all parties to determine which parameters to monitor, how often to sample data, and how long to preserve the data. The working group in this area is developing a standard approach for systems that would monitor, collect, process and present operating status and fault information for rail vehicles. A standard diagnostic system is projected to save the industry about $78 million annually in maintenance costs.

The most sophisticated on-board diagnostic systems are in place on Boston's Red Line Cars, new cars delivered for service on SEPTA's (Philadelphia) Market-Frankfort line, and cars remanufactured for New Jersey Transit. R142 rail cars being designed for New York and Amtrak's planned high-speed cars will also include a comprehensive specification for an on-board monitoring and diagnostic system.

Helping to promote on-board diagnostics are event recorders. Required by the Federal Railroad Administration (FRA) for use in railroads and commuter rail applications, on-board event recorders are becoming more prevalent in transit applications. The monitoring of train events for accident reconstruction purposes can also be used for diagnostic purposes.

*TCIP for Rail Transit*

A separate working group is developing data message sets that will be compatible with Transit Communications Interface Profiles (TCIP). Funded by the U.S. DOT, TCIP is a program under ITS that will allow data generated from various public transit sectors to be exchanged with other elements of ITS.

Before the exchange can take place, however, data messages must be clearly defined. The development of standardized data message sets will ensure that terminology used to communicate between trains is understood in the same manner by all ITS participants. Additional informantion on TCIP is provided in Chapter 6.

# ELECTRICAL SYSTEM MULTIPLEXING

The term "multiplexing" applies to a broad range of electronic integration. This chapter focuses on electrical system multiplexing, which uses microprocessors and proprietary data networks to control basic on/off electrical devices such as lights, turn signals, horns, and similar "hotel" type functions.

## SUMMARY

Transit buses contain many electrical devices that need to be switched on or off depending on operating conditions. As noted earlier, the traditional means of controlling electrical devices is through relay logic. With relay logic, power and ground signals used to activate and deactivate devices are carried through individual "hard" wires. Relays are used to receive electrical current from one switch and "relay" it to another device. Each connection point has the potential for failure, which must be traced step-by-step to discover.

Multiplexing replaces relay logic with a computer-based system to control electrical functions. It performs similar tasks with less wiring and fewer relays, and features its own built-in diagnostic system. The monitoring capabilities of multiplexing also allow it to oversee certain functions and trigger alerts to the operator. Multiplexing is installed as an entire system by the bus builder. Furthermore, its operation is completely invisible to the bus operator.

Multiplexing has been adopted from other industries and uses its own proprietary operating system. Since they perform basic on-off type functions such as activating lights, the proprietary nature of multiplexed systems does not impact electrical products on the bus. For example, the switch that activates a particular device and the device itself are not affected by multiplexing's operating system. As a result, transit agencies can continue to purchase switches and electrical products such as lamps from traditional sources. What they cannot do, however, is exchange components such as microprocessors and modules from one multiplex system to another.

There are two known multiplexing approaches currently offered for bus applications. One system disperses control functions throughout the bus. Another uses a centralized processing system. Despite the differences, multiplexing systems provide many benefits in common. Included are the ability to modify the electrical system without adding wires, relays and connectors, and the use of indicator lamps to simplify diagnostics.

## TRADITIONAL ELECTRICAL SYSTEMS

Before describing multiplexing or "mux" in greater detail, a brief explanation of traditional electrical systems will make the benefits easier to understand. To function, each electrical device needs a continuous "circuit" of both power and ground from the battery. Switches and relays are used to "open" or "close" the circuit depending on whether the device is "off" or "on." A relay is nothing more than a heavy-duty switch that receives power or ground from one switch and "relays" it to control (i.e., activate or deactivate) another device.

Relays can also be used to control functions under certain conditions. For example, to help reduce windshield glare, a separate relay can be added to extinguish a single row of lights just behind the windshield whenever the door is closed. The use of relays to control electrical functions, known as relay logic, requires individual wire connections. Figure 4-1 illustrates how four electrical devices are connected in a traditional point-to-point "hardwired" electrical system.

As an increasing number of electrical control functions are added, the number of wires, relays, and connectors also increases. In a 40-foot bus, the vast amount of equipment increases electrical system complexity and bus weight. If one of the many wire connections should come undone and create a loss of continuity because of corrosion, poor crimping, or loose terminals or connectors, it must be traced step-by-step back to the faulty connection.

Additionally, specific features requested by each agency require a different configuration of wires and relays, which adds production time and cost to each bus order. According to one bus manufacturer, the electrical system can consume up to one half the engineering time to design, and up to 15 percent of the vehicle production time to build, install and troubleshoot (38).

## MULTIPLEXING: THE BASICS

Multiplexing simplifies the electrical system by replacing the maze of relay-logic control with software. In a multiplexed system, a microprocessor monitors

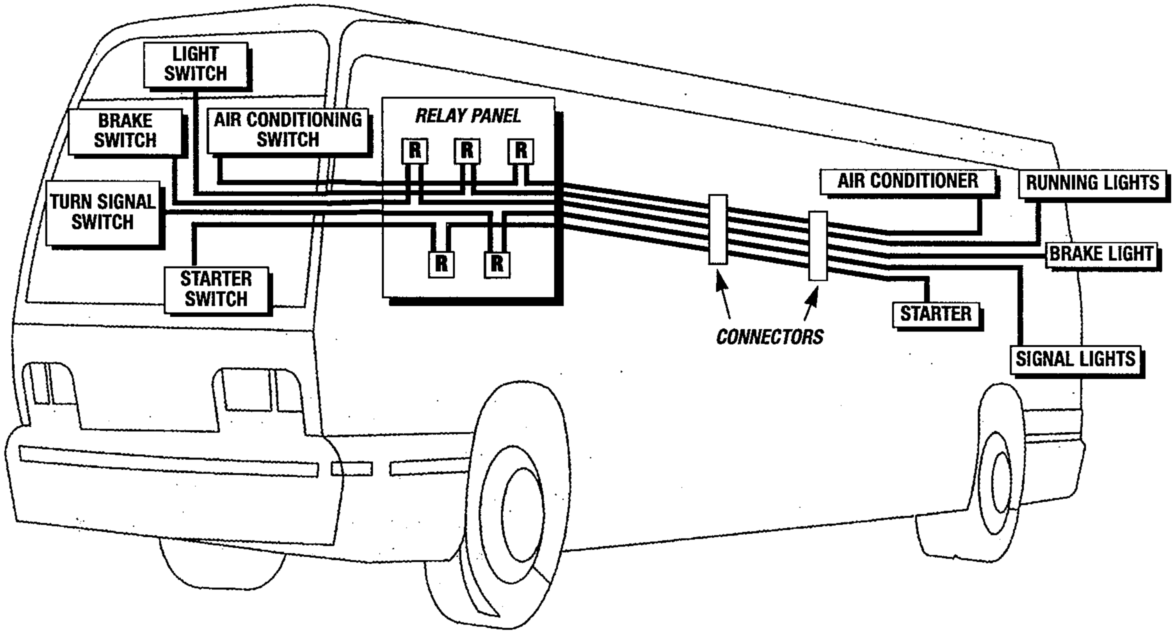


*Figure 4-1* ***Traditional "hardwired" electrical system with separate wires connecting switches, relays, and electrical devices.***

switch positions, and controls devices accordingly. Instead of using individual wires and relays to control electrical devices, multiplexing uses its own data network and signaling system.

Essential to multiplexing are the various input/output (I/O) modules strategically located throughout the bus. Typical locations include the operator's area, front door, rear door, and engine compartment. If the operator activates the brake pedal, for example, an I/O module at the front of the bus sends a signal to the main controller (i.e., microprocessor). In turn, the controller signals an I/O module at the rear of the bus instructing it to deliver battery power to the brake lights. I/O modules are important because they process control signals from the multiplexing operating system, and also direct electrical current to specific devices when given the appropriate command. Figure 4-2 illustrates the basic concept of electrical system multiplexing.

## MULTIPLEXING: THE DETAILS

There are two popular approaches to electrical system multiplexing: centralized control and decentralized control (22, 39). In a centralized control system a single processor controls the various I/O modules, which collect information and react to commands. In a distributed control system, I/O modules also have processing capabilities and can initiate commands locally for faster reaction time. Both systems use a single cable to send and receive control messages. Centralized control systems use a two-wire cable; distributed control systems use a six-wire cable. To simplify the explanation of multiplexing, a centralized control system will be described in this chapter.

There are three main components to a typical centralized-control mux system: main controller, I/O modules, and the data cable. The main controller serves as the system's "general in charge," continually scanning all conditions and executing commands based on its internal software program. I/O modules are "soldiers in the field," gathering intelligence on the status of inputs (i.e., switch positions), and making the information available to the main controller. The controller then processes all inputs and sends a signal back to the output portion of the I/O modules to execute commands.

Since I/O modules are also supplied with power and ground current from the bus batteries, internal relays within the modules are used to distribute current to specific devices when instructed by the main controller. The relays used in the I/O modules can be solid-state, electro-mechanical, or a combination of both.

A data cable carries messages between the main controller and the I/O modules. It consists of a small number of wires that can send multiple signals in either direction (similar to a telephone line). Signals sent within the wires can emit or be affected by electromagnetic interference or radio frequency interference (EMI/RFI) generated by power lines, radio signals, radar, and various on-board electronics. To protect

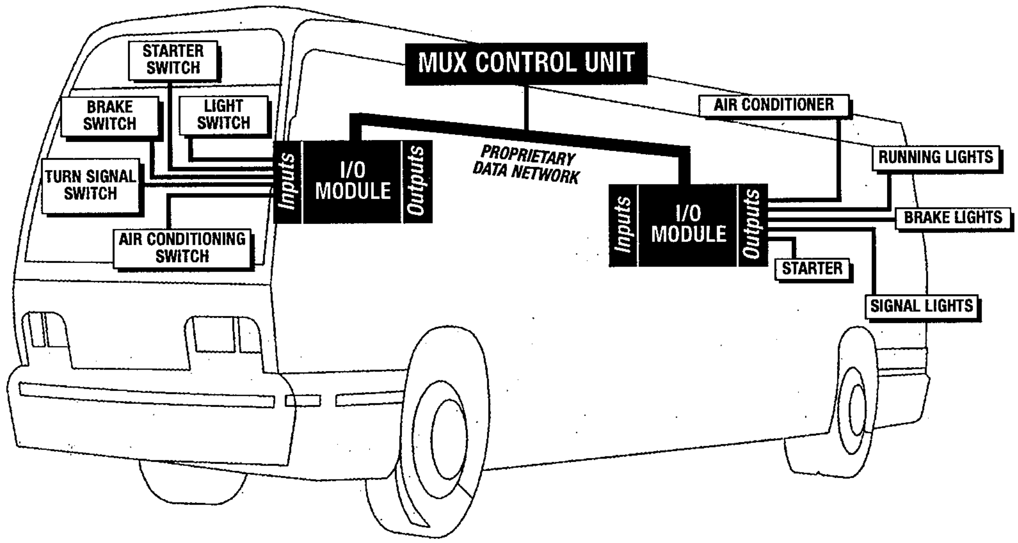


*Figure 4-2* ***Instead of running individual wires to each device, multiplexing uses a controller and satellite modules to control several functions over its own data network.***

against EMI/RFI, data cables are shielded to minimize the reception or radiation of electromagnetic energy.

### Mux, Start Your Engine

In a mux system the switch that initiates a command and the device that becomes activated remain the same. It is the connection between them that differs. The engine starting circuit is used to describe multiplexing in greater detail.

*Traditional Approach*

In a traditional wiring system, the starter is activated by sending electrical current through a series of relays to ensure that the engine starts under safe conditions. Relays must be individually wired from the transmission to indicate that it is in neutral, the alternator to ensure that the engine is not already running, and from an engine compartment switch to ensure that a mechanic is not working there. When all relays are activated correctly, continuity exists and electrical current is carried through the wiring to engage the starter.

*Multiplexing Approach*

Except for the starter switch and the starter motor, mux operates much differently. When the engine switch is depressed, electrical current is sent through a wire to the "input" portion of the closest I/O module. Using the data cable to constantly scan all signals, the controller recognizes that an electrical current is present at the I/O module.

The controller then uses its programmed logic to search for conditions that must exist at other input addresses (i.e., the transmission is in neutral). If the appropriate signals are received, the controller signals the I/O module nearest the starter to engage the starter.

A schematic illustrating how a centralized-control mux system uses battery current and its own signaling system to control electrical devices is shown in Figure 4-3. The starter circuit has been isolated to serve as a representative example.

Those accustomed to reading wiring schematics can follow Figure 4-3 without much difficulty. For others, a brief explanation will help:

- Power (+) (12 or 24 volt) and ground (-) current from the battery is provided over separate "hard wires" to the main controller and each I/O module.
- A two-way cable (i.e., data network) sends proprietary signals to and from the I/O modules and main controller (it does not carry battery power or ground).
- A scanner (part of the main controller) uses the data cable to continually scan the input signals from all I/O modules.
- When the operator depresses the starter switch, power or ground is sent to a specific address on an I/O module located in front of the bus.
- A signal from the I/O module is sent over the data cable to inform the main controller.
- When the controller receives the signal, it uses its programmed logic to scan the inputs from the neutral safety switch and rear-start position switch.

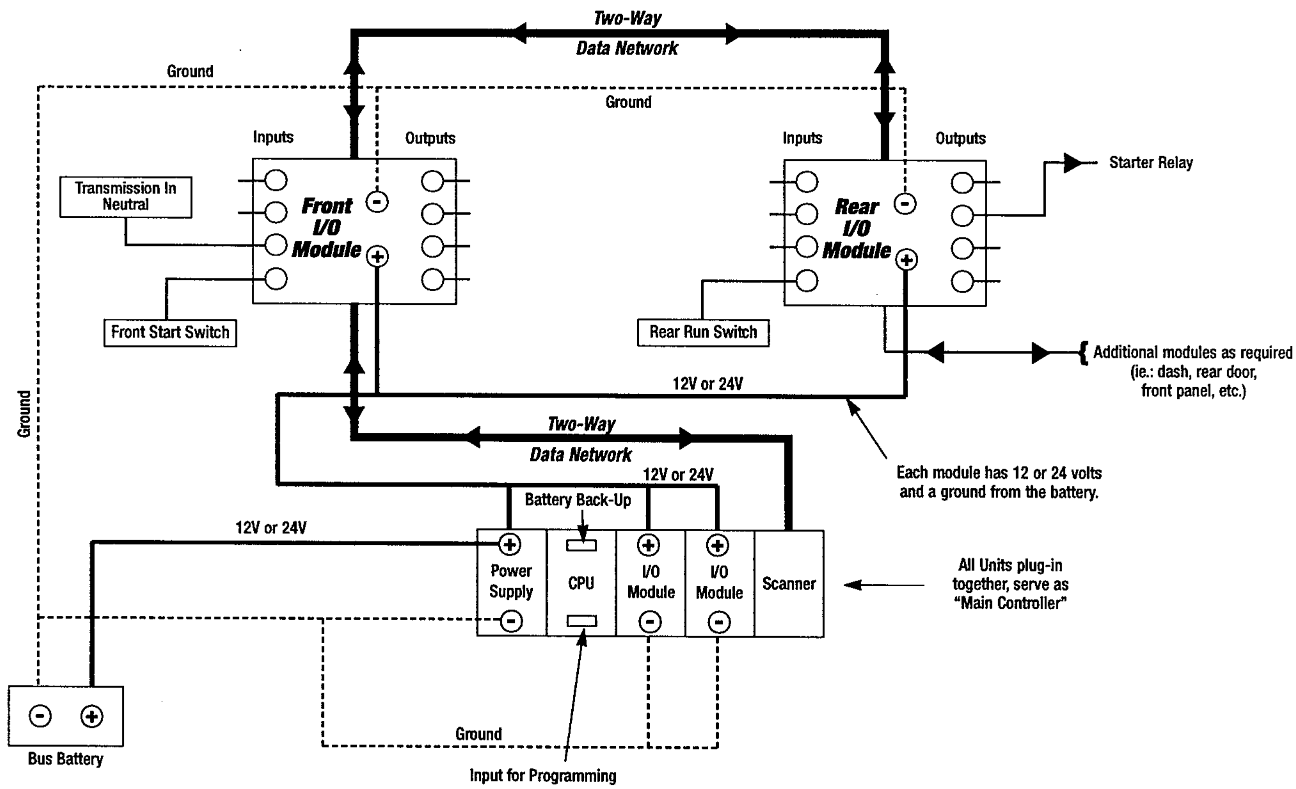


*Figure 4-3* *Schematic showing how multiplexing uses its own data network and the battery's power and ground current to control the engine starting circuit.*
*(Courtesy of David Harvey, Milwaukee County Transit)*

- If all conditions are satisfied, a command signal is sent via the data cable to the output side of an I/O module.
- Once the output side of the I/O module receives the command, relays inside the module direct power to the starter relay.

## Ladder Logic

Like other computers, the mux processor uses a program to perform its duties. The program used by mux is called ladder logic. A ladder logic schematic closely resembles a traditional relay-based electrical system schematic with some major differences. Whereas a hardwired schematic shows the actual flow of battery current, a ladder logic schematic represents instructions written for the software application.

Another difference is that in a traditional electrical diagram, devices are either "open" (contacts open, no current flow) or "closed" (contacts closed, current flows through). In a ladder logic program, instructions are either "true" or "false," although the two sets of terms are often used interchangeably.

Figure 4-4 shows the ladder logic of a single control function. Each rung of the ladder represents the condition(s) that must exist — or be "true" — before a particular electrical device can be activated. Read left to right, ladder logic begins with one or more condition instructions or inputs (i.e., switch position is on), and at least one control instruction or output (i.e, energize light). The symbols for frequently used condition instructions include "normally open" ( ] [ ) and "normally closed" ( ]/[ ). When all conditions are true (i.e., a normally closed condition is in fact closed), logical continuity exists and a control signal is given to energize a particular device.

When any of the condition instructions are false (i.e., a normally closed condition is open), logical continuity does not exist and the control instruction remains in the "off" or de-energized state.

## Electrical Changes Made Through Software

One of the most significant benefits of mux is its ability to make changes without running separate wires or adding relays. Instead, changes are programmed into

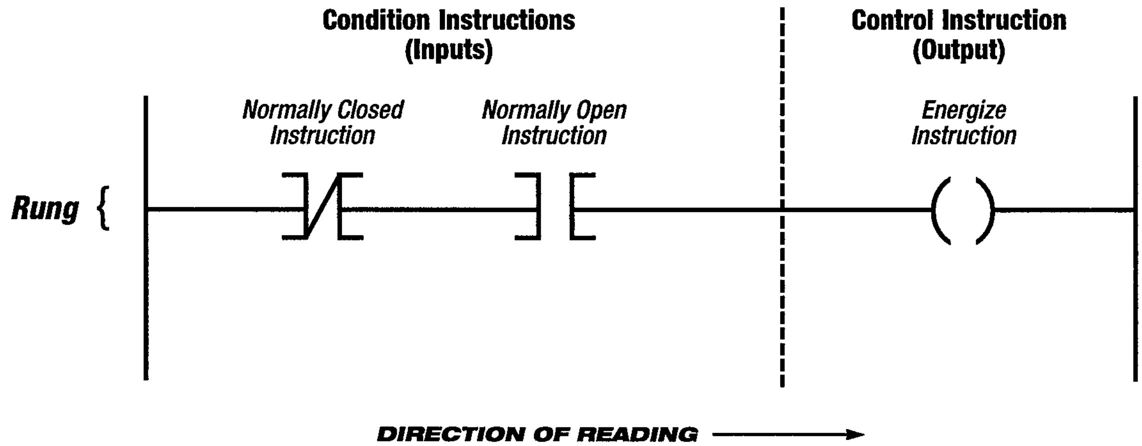


*Figure 4-4* *Ladder logic instructions.*

the ladder logic software using a laptop computer. For example, if an agency wanted to prevent the starter from overheating, the mux controller could be programmed to de-energize the starter after 10 seconds of cranking regardless of the operator's actions. Since changes made to the software program are done on a PC, ladder logic schematics can be printed to keep a current record of bus configurations.

### LEDs Simplify Diagnostics

Another benefit of multiplexing is its self-diagnostics capabilities. In a traditional wiring system, the mechanic must use a test lamp or similar instrument at each connection point to determine why a particular device is not responding to a switch being turned on. In a multiplex system, the main controller and I/O modules have light emitting diode (LED) lamps at each input/output address for simple visual inspections. The LED lamps illuminate when the address is active, providing maintenance personnel with a visual indication if signals are being received. When a malfunction does occur, the LEDs provide a quick means of fault detection. Figure 4-5 illustrates how LEDs are used to indicate if signals have been received.

Connecting a laptop computer or hand-held tester to the main controller provides another method of tracking faults. In about 85 percent of all cases, however, visual inspection of the on-board LEDs typically result in fault identification (22). If a failure involves an I/O module or the main controller, they typically are not field repairable and must be removed and replaced as an entire unit.

### Two MUX Approaches

There are two known multiplexing approaches offered for North American transit bus use. Both designs have been developed for industrial applications and are readily adaptable for use in transit bus environments. Each uses its own components, along with a

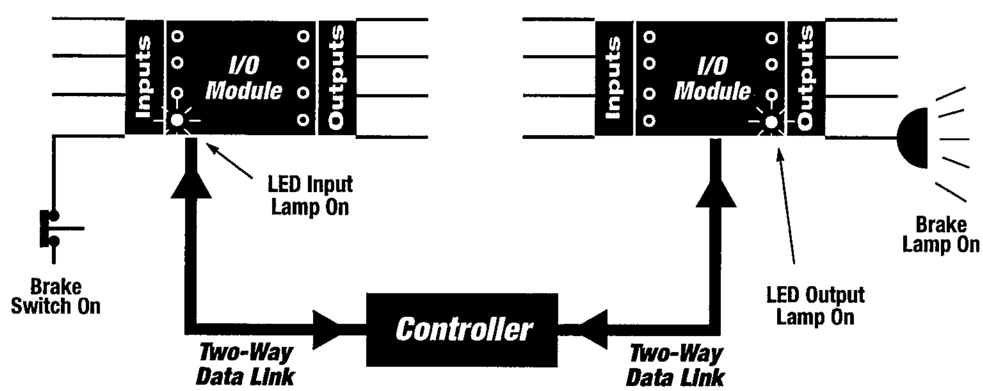


*Figure 4-5* *LED lamps provide visual indication of control signals.*

proprietary communication protocol, to operate. Additional features and characteristics that the two systems share in common include:

- Ability to monitor and control the on/off status of any electrical component;
- Use of LED lamps to indicate input/output status to simplify diagnostics;
- Use of a PC to add specific features to the electrical system without adding wires, relays, and connectors;
- Use of "ladder logic" as the operating program;
- Use of a power supply module to ensure that the system is provided with "clean" power; and the
- Ability to easily plug in additional product-specific components such as I/O modules.

Despite the similarities, there are some major differences. The primary difference is that one system uses centralized control, while the other uses distributed control. Another major difference involves the current load each system can handle without requiring traditional relays. Systems are capable of handling current loads from one amp to 10 amps. After that, additional relays are required.

Gateway modules permit transfer of data between multiplexing's own proprietary data networks and other protocols such as those developed by SAE (i.e., J1708). In addition, robust data networks such as SAE J1939 described in the next chapter may be configured in the future to control electrical functions.

# THE ROLE OF STANDARD DATA NETWORKS IN ELECTRONIC INTEGRATION

The last chapter described how multiplexing uses proprietary data networks to control basic on/off switching in the Electrical Level. This chapter describes how standard or "open" networks developed by the Society of Automotive Engineers (SAE) are applied to integrate components in the Drivetrain and Information Levels. Although other networks could be applied, this chapter focuses on SAE networks for four main reasons:

(1) SAE networks are already used in buses to integrate drivetrain components;

(2) The vehicle area network (VAN) program has selected a modified version of SAE J1708 as its choice for Information Level integration;

(3) Transit agencies are writing specifications that include Information Level compatibility with J1708; and

(4) Heavy-duty trucking has successfully applied SAE networks to integrate on-board components, including those relating to vehicle location, communication, and radar collision avoidance.

## SUMMARY

The transfer of data between electronic devices usually involves a reference to three terms, which are often used interchangeably: communication protocol, data network, and system architecture. For the purposes of this study, a communication protocol is a set of rules that define how messages are coded and transmitted between electronic devices. A data network is the two-way cable and framework that uses the protocols to deliver messages between vehicle subsystems (i.e., engine and transmission, AVL and farebox, etc.).

System architecture is a much broader framework for information exchange through which larger systems are integrated (i.e., bus and transit agency, transit agency and other municipal agencies, etc.). On a national level, the ITS Architecture described in Chapter 6 seeks to ensure that data will flow in a uniform manner between all ITS elements. On a transit agency level, a well defined architecture permits an efficient exchange of data between buses and all agency departments.

This chapter focuses on data networks, the framework used to exchange data in an orderly fashion between components in the Drivetrain and Information Levels. Networks can be based on varying degrees of proprietary (i.e, closed) or standard (i.e., open) communication protocols. The degree to which networks are open or closed depends upon how they interface with seven layers of a reference model developed by the International Standards Organization (ISO). A fully open network is one where documentation for all seven layers is made available to any supplier. A fully closed network is one where all interface specifications are proprietary — not available for public use.

Although a data network is described as "open," it does not necessarily use all seven layers of the ISO reference model. For example, SAE networks are considered open yet J1708 uses only three layers, which was sufficient to meet all network needs for trucks and buses at the time. SAE J1939, developed for new-generation drivetrain components, makes use of all seven layers, as do other networks. The better defined the network, the more flexible it can be in accommodating new applications.

Regardless of how well defined, open data networks allow components of different makes to be exchanged in a "plug and play" fashion. This standardized approach allows the end user to choose from a variety of products. It also allows components to be upgraded easily, an important consideration for a 12-year bus life cycle.

Until recently, most Information Level electronics have been designed around proprietary systems. However, a program is underway to create a standardized VAN specifically for integrating Information Level components. VAN is based on the existing SAE J1708 data network, which is being modified for transit bus use.

Some question the ability of J1708 to handle Information Level integration. Proponents, however, argue that the question is not whether J1708 is the best network available — clearly there are faster and more flexible networks to choose from. The real question is whether J1708 is the most appropriate and cost-effec-

tive solution for bus applications. The question of J1708's appropriateness for bus applications will (hopefully) be answered in the near future. The VAN section of Chapter 6 provides additional information on J1708's application to transit buses.

An overview of data networks reveals why they were developed, how they operate, and why they are changing. The insight is especially useful as agencies attempt to integrate components found in the Information Level. Unlike multiplexing and drivetrain components integrated by the bus builder, Information Level integration requires greater involvement by the transit agency.

## OPEN SYSTEMS INTERCONNECTION (OSI) REFERENCE MODEL

The Open Systems Interconnection (OSI) reference model was developed by the International Standards Organization (ISO) to standardize the communication of data between computer systems. This universal model defines the specific procedures, or "protocols," that developers of data networks must follow when transferring information between electronic devices. The reference model is divided into seven different interface "layers." The layers define the manner in which a system, subsystem or component can interpret information transmitted to it by another. Included are requirements for:

- Interfacing a device on the network to a cable (i.e., Physical Layer);
- Interfacing the cable with higher levels of the subsystem, including how source and destination fields will be identified (i.e., Data Link Layer); and
- Interfacing specific software applications to the open systems interconnection environment, including provisions for file transfer (i.e., Application Layer).

All seven layers and related functions of the OSI model are summarized in Appendix B. A fully open network is one where documentation for each of the seven layers resides in the public domain. A fully closed network is one where interface specifications are proprietary and not available for public use. While some networks use all seven layers of the OSI model, others do not. The better defined the network (i.e., uses many or all seven layers with specifications for each available for public use), the more flexible the network can be in accommodating new applications.

The concept of open data networks is important because it allows components of different manufacture to be exchanged in a "plug and play" fashion. A video cassette recorder serves as a good analogy. Regardless of the brand, any VCR can "plug" into a television to "play" a video tape. Open access to the network is significant because it gives the end user a variety of products to choose from at competitive prices. It also provides additional flexibility when upgrading to new technology. On the other hand, closed networks restrict access to the network and only allow certain manufacturers to use it.

Several reference books are available that provide additional information on the OSI model, along with the open-architecture networks developed from it (40,41,42,43).

## SAE FAMILY OF DATA NETWORKS: AN OVERVIEW

SAE data networks developed for heavy-duty trucks and buses conform to certain protocols set forth in the OSI model. Before describing each SAE network in detail, a brief overview and chronological perspective offers insight into why certain SAE data networks are being applied to different bus levels.

In 1986, SAE began the task of standardizing the exchange of data for heavy-duty trucks. The result was SAE J1708, which defines the basic hardware and conditions required for on-board data exchange (44). With the J1708 backbone in place, SAE completed the network with J1587 to add general on-board information sharing and diagnostic functions, thus making J1708 an operable network (45). Whenever J1587 is mentioned, it is assumed that J1708 is included (i.e., J1708/J1587).

Using a home computer as an analogy, J1708 determines how the color monitor and keyboard will connect to the computer, while J1587 defines how each component will function. Originally intended for heavy-duty trucks, J1708/J1587 was adapted for bus use in 1992.

Since drivetrain component messages consume about 70 percent of the network's capacity, SAE developed J1922 as another protocol that could operate over a J1708 network (46). The J1922 addition to J1708 was developed exclusively for first-generation engine, transmission, and retarder functions. Use of a separate network was deemed necessary due to the safety critical nature of drivetrain components, and to improve the data throughput rate. First applied to trucks, SAE J1922 was also used on buses.

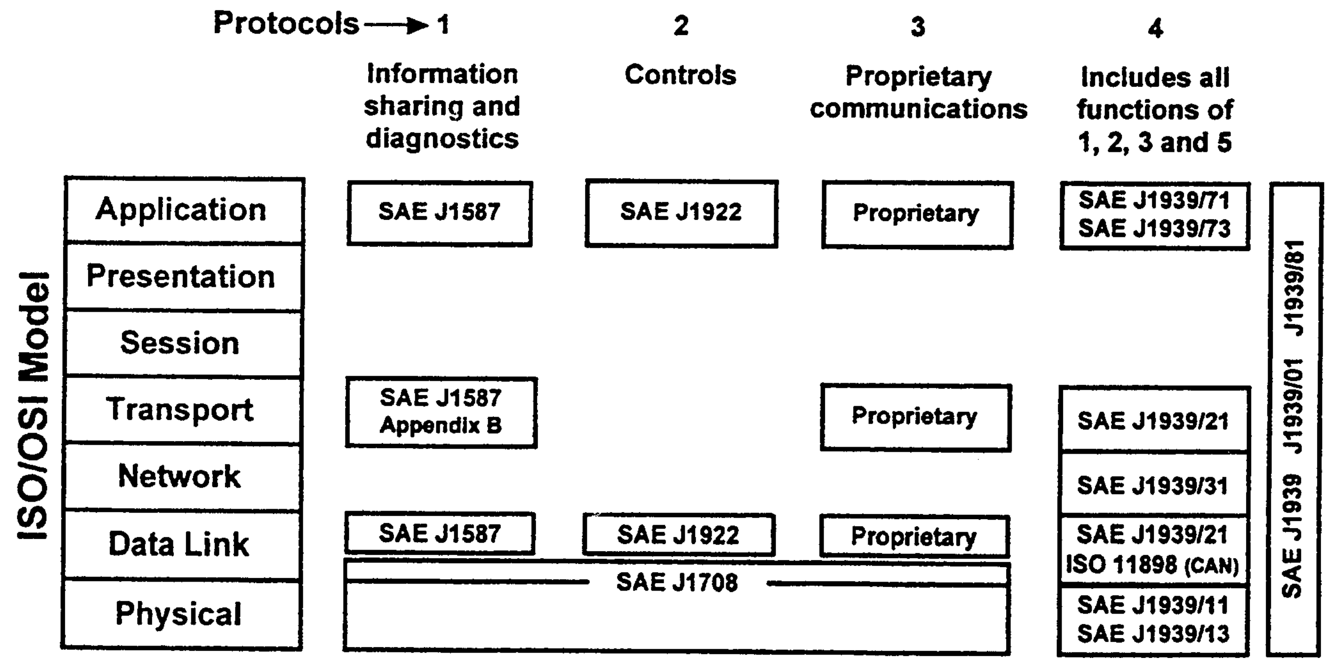


*Figure 5-1* *SAE Documents mapped to the OSI model. (Courtesy of Cummins Engine Company)*

In the constantly changing world of electronics, the SAE J1708 family of networks became inadequate for advanced drivetrain integration. For one, J1708 lacks the speed necessary to handle some of the complex data interactions inherent with anti-lock brakes and traction control. Further, the growing number of electronic components added to the vehicle requires additional J1708 networks to accommodate them, adding cost and complexity to vehicles. To resolve this, SAE is developing a new data network called J1939, which is being released as several documents because of its complexity (47).

The J1939 network is capable of handling all of the requirements currently satisfied by J1708/J1587/J1922 with excess capacity to address future requirements. Drivetrain components are the first to use J1939 as a replacement for J1708/J1922. SAE J1939 is based, in part, on the Controller Area Network (CAN) data network developed and licensed by Bosch for European vehicles (48).

Figure 5-1 shows the various SAE documents mapped to the OSI model (49). As Figure 5-1 illustrates, SAE J1708 and J1587 interface with three of the seven OSI layers, which at the time of their development were deemed sufficient to meet data communication needs. The more robust J1939 network spans all seven layers.

In addition to data networks, SAE has issued a recommended practice concerning environmental conditions that electronic equipment must be capable of enduring. Called J1455, it defines test methods for temperature, humidity, dust, washing, mechanical shock, and other factors pertaining specifically to the environment of truck and bus electronic systems (50).

### 3-Speed Data Transmission

SAE data networks developed for heavy-duty trucks and buses are classified by their data transmission rate or speed. Table 5-1 shows the class, speed, application, and corresponding designation of critical SAE data networks.

The use of a high-speed Class C data network such as J1939 is 26 times faster than a low-speed Class A network like J1708, which is analogous to driving an automobile at 100 mph versus 4 mph. This difference in travel time, referred to as latency, is critical for safety and real-time control functions. For example, when the ABS system detects a locked wheel it must have the required speed to transmit, receive, and process data quickly to avert a potentially dangerous situation. Delays in data transmission could cause a wheel to remain locked for an extended period of time, resulting in a potentially out-of-control condition. As a result, most drivetrain components are now being integrated around the high-speed J1939 network.

#### *Is J1708 Fast Enough?*

One of the issues surrounding the applicability of J1708 to Information Level integration involves its speed. Some argue that the use of a low-speed Class A

| Class | Speed | Application | SAE Data Network |
|---|---|---|---|
| A | Low speed, less than 10,000 bits/second | 1) Used in the "Drivetrain" Level for 1st-generation engine, transmission, etc.<br>2) Limited "Information" Level application for AVL, headsigns, fare collection, etc | 1) Typified by the J1708 family of protocols including J1587 & J1922<br>2) Typified by J1708/J1587 used in the Vehicle Area Network (VAN) |
| B | Medium Speed, from 10,000 to 125,000 bits/second | Used for general data sharing and diagnostics in automobiles | Typified by J1850 |
| C | High Speed, from 125,000 to 1,000,000 bits/second or greater | Used in the "Drivetrain" Level for next-generation control of engine, transmission and brake systems | Typified by J1939 |

*Table 5-1 The three classes of SAE data networks based on speed.*

network such as J1708 is adequate and cost-effective for integrating AVL, destination signs, fareboxes, and similar components. Others claim that it is not fast enough, especially when sending data in real time.

Proponents of J1708 contend that data transferred back to the transit agency in real time is limited by the radio system, not the on-board data network. With a transmission speed of 9600 bits per second (baud), the low-speed SAE J1708 data network is said to be more than capable of transferring data over a bus radio system with a typical baud rate of 4800. Additional information concerning SAE J1708 and its transmission speed is provided in the VAN section of Chapter 6.

### No Main Controller

Unlike multiplexing described earlier, SAE data networks do not use a microprocessor to manage data communications among the various components. Instead, the electronic control module (ECM) of each component is equipped to manage the flow of data according to established protocols.

Although each device is responsible for managing data over the network, a microprocessor such as a VLU can be added to the network like any other device. It too can "listen" to messages transmitted over the network. With its abundant processing capabilities, the VLU can be programmed to make use of data in a variety of ways. For example, it can monitor several operating conditions, store them in memory, and send alarms in real time over the radio to the agency's facility.

## SAE NETWORKS: THE DETAILS

### SAE J1708

As noted earlier, J1708 identifies the minimum hardware and procedural requirements for routing messages over the network. It establishes a method for determining:

- Which device is communicating (i.e., engine, farebox, etc.);
- The length of time that each device is allowed to communicate;
- Which device has priority in accessing the network when two try to gain access simultaneously; and
- That the message was received correctly should there be problems in transmission.

All on-board electronic components are connected to the network with a pair of twisted wires (i.e., cable) that carry data in both directions. SAE J1708 specifies the requirements for the cable itself, along with connectors, acceptable voltage and current limits, and number of subsystems allowed on the network. Up to 20 subsystems are permitted to send messages over the network. When one wants to transmit a message, it must wait until the network is idle (i.e., not carrying another message for a specified period of time). Once the network is free, the message is sent using a priority-ranking protocol.

If two or more messages are sent simultaneously, a contention resolution procedure determines which message gains access first. The procedure begins by cancelling both messages. After a specified delay period, the message with the highest priority is allowed to re-access the network first. The secondary message is then allowed to regain access to the network when idle. This contention resolution procedure of cancelling both messages delays the transmission of data, which makes J1708 unacceptable for some time-sensitive control functions such as ABS.

The number of individual SAE J1708 networks that can exist on a vehicle is unlimited. It is not uncommon for a modern transit bus to have multiple J1708-based networks: one (or more) to integrate drivetrain-related components, and one to integrate Information Level components.

### SAE J1587

SAE J1587 completes J1708 by defining the protocol that devices on the network will use to communicate. For example, something as simple as a date (i.e., 02-11-98) can not be communicated accurately unless it was known which digit pairings correspond to the month, day and year. SAE J1587 clearly defines how messages are transmitted and received by each device on the network.

Examples of the types of messages initiated and received by electronic components connected to the J1708/J1587 network include:

- Vehicle and component information relating to operating performance status and diagnostics;
- Routing and scheduling information, which relates to the planned or actual route of the vehicle, current vehicle location, and ridership data;
- Information pertaining to operator activity; and
- Freight status and billing activities (trucking use only).

Each message has an assigned priority based on an eight-level scale. This allows urgent messages to have preference over non-critical correspondence. SAE J1587 also supports file transfers for uploading and downloading larger amounts of data between the bus and remote locations. The protocol is designed to transfer files when the network is idle to avoid tying up the data network from normal message traffic.

In addition to operational messages, J1587 also transfers component performance data including an indication if a device is functioning properly or experiencing failures. SAE J1587 also "reads" the serial number for each device, allowing software and data revisions to be made easily over the network.

SAE is constantly defining new messages for J1587 through requests from its truck and transit members. New message sets being defined for transit include those for ITS-related devices such as fare collection, AVL, traffic priority, next-stop annunciators, on-board signage, and operator control heads.

### SAE J1922

SAE J1922, which also requires a J1708 backbone to operate, is used on the first generation of drivetrain components. While appropriate for early integration, SAE J1922 is becoming obsolete because its slower speed cannot accommodate the number of data messages generated from the growing number of drivetrain control functions. In its place, manufacturers have applied the faster-speed J1939 network.

Until all equipment is compatible with J1939, however, bus manufacturers typically run a J1939 network alongside various combinations of the J1708-based networks. As noted earlier, operation of these multiple networks is seamless to the transit agency.

### SAE J1939

SAE J1939, "Recommended Practice for Serial Control and Communications Vehicle Network," is a high-speed Class C general purpose network. It is being developed to handle information sharing, diagnostics, multiplexing, and specific communications that product manufacturers want to keep as proprietary. Based in part on the European CAN protocol, it will satisfy all of the functions currently performed by the J1708 family of data networks with excess capacity to handle future needs. Initial work on J1939 began in 1986. Today, much of this network is complete.

Manufacturers of drivetrain components are the first to implement J1939 on their most recent product offerings. The move to J1939 is needed to accommodate the real-time requirements of ABS and traction control, as well as the growing number of drivetrain-related control functions.

SAE J1939 has a data rate of 250,000 bits per second, making it much faster than J1708. SAE J1939 also permits a connection of up to 30 units compared to a maximum of 20 for a J1708 network. Further, J1939's non-destructive message arbitration process adopted from CAN ensures that data transmission time is fully utilized.

SAE uses a labeling format where all documents begin with J1939, followed by a slash and a two digit number (i.e., J1939/12). In most cases, the first digit corresponds to the applicable OSI layer, while the second denotes additional capabilities or an alternate solution. Figure 5-1 shown earlier maps the various J1939 documents to the seven OSI layers. Appendix C lists the titles for the various J1939 documents as defined by SAE (49).

Once J1939 is fully developed, it will likely be configured to include other control functions as well. Future applications for J1939 may include power control functions currently handled by electrical system multiplexing, service tools, diagnostics, and operator instrumentation functions. Heavy-duty trucking will be the first to expand the use of J1939. Concerning transit buses, J1939 is already being applied to drivetrain integration. Application to the Electrical Level (i.e., multiplexing) may follow, depending on J1939's success in trucking and how current multiplexing systems develop. Information Level integration, however, continues to center around VAN using a modified version of SAE J1708 as its foundation.

### SAE J1455: Environmental Practices

SAE J1455 is not a data network. Instead, J1455 serves as a Recommended Practice (RP) to aid designers of electronic systems and components by providing guidance that may be used when developing environmental design goals (50). The RP covers climatic, dynamic, and electrical environments that influence the performance and reliability of electronic equipment used in heavy-duty vehicles such as trucks and buses.

Environmental factors and test methods are organized under 13 headings. Included are: temperature; humidity; salt spray; steam cleaning and pressure washing; altitude; mechanical vibration; shock, dust, sand and gravel bombardment; and other conditions. The RP combines some of these factors to ensure that real life environmental conditions are duplicated. For example, the suggested test method for humidity includes a combination of both high- and low-temperature exposure.

Vehicle environment is classified by specific areas that include the engine compartment, interior, chassis, and exterior portions of the vehicle.

## SAE NETWORKS AND DRIVETRAIN INTEGRATION

All electronically controlled drivetrain components installed in U.S. buses exchange data over one or more SAE-developed networks. The use of dedicated networks to support drivetrain components ensures protection from components and systems not considered vital to the vehicle's driveability.

Manufacturers are currently in a state of transition regarding the application of SAE networks, producing equipment that supports the transfer of data on the J1708 family of networks (i.e., J1587/J1922) and the new J1939 standard. Communication ports on each component convert J1708-type data into J1939 data and visa versa. As drivetrain components become updated and more experience is gained with J1939, J1708-related connectors and circuitry will not be needed.

Exchanging data between the engine, transmission, retarder, ABS/traction control system, accelerator pedal, and brake pedal improves both driveability and safety. Instead of acting as autonomous units, driveline components can perform tasks in unison. For example, when the ABS system reacts to a locked wheel, it can also request that the braking effect of the retarder be turned off to help prevent skidding.

The illustration of Drivetrain Level integration shown in Figure 5-2 has been simplified with a single J1939 network. In fact, multiple networks could be used to support the exchange of drivetrain-related data in a seamless manner.

## SAE NETWORKS AND INFORMATION LEVEL INTEGRATION

Developed specifically for truck and bus applications as an open network, SAE J1708/J1587 can serve as a logical platform for standardizing the exchange of data between components typically found in the Information Level. The integration could also be accomplished through the application of other open networks, a proprietary network, or a combination of the two. Until recently, the integration was based on proprietary networks. However, some manufacturers and integrators are actively marketing components and systems that are compatible with J1708. Others are taking a wait-and-see approach to determine which network emerges as the industry norm.

Efforts to standardize the integration of Information Level components around J1708 are being undertaken by the Vehicle Area Network (VAN) program. Several VAN demonstrations are underway at agencies including Houston Metro, Ann Arbor Transportation Authority, Los Angeles County MTA, and MTA New York City Transit (21, 51).

An integral component of VAN is the on-board VLU microprocessor. In a typical installation, the VLU

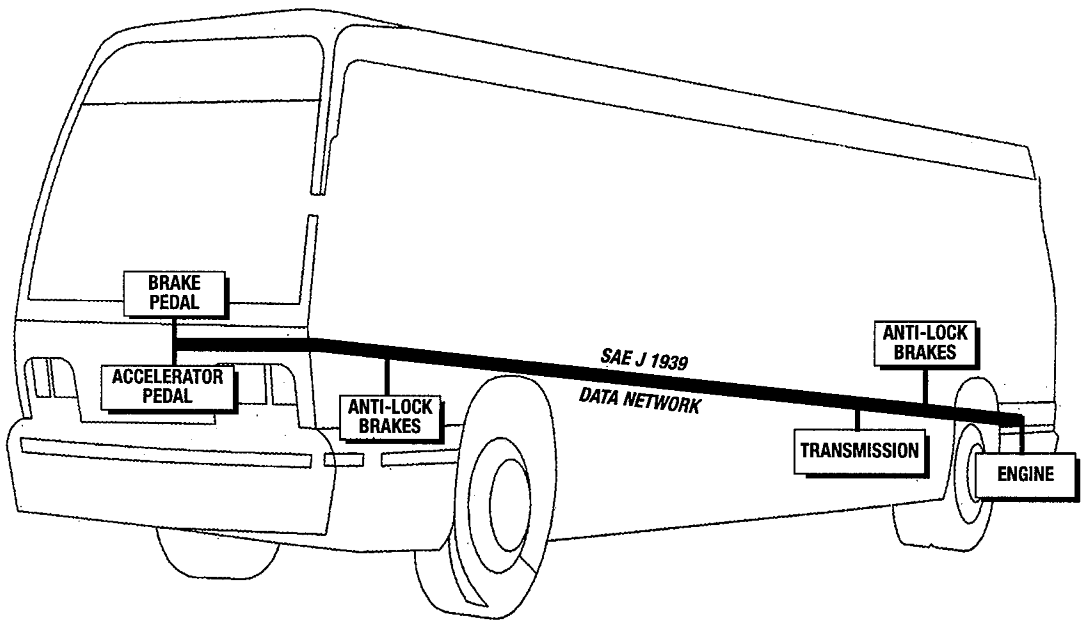


*Figure 5-2 Drivetrain integration achieved through SAE J1939.*

is a central component of the AVL system. In other applications where AVL is not used, the VLU is a stand-alone device such as an event recorder. A VLU could also be used as a central processor for a next-stop annunciator system that includes future capabilities for vehicle location and component integration.

The use of a data network such as J1708/1587 to exchange information between AVL, VLU, fare collection, radio, passenger information, and other systems provides a variety of opportunities to enhance bus service. Examples of functions made possible through integration include:

- Combine passenger information systems with AVL to provide automatic next-stop audio and visual announcements;
- Combine fare collection with passenger counters, passenger information systems and AVL to identify passenger trends more accurately;
- Combine on-board cameras and AVL to store video images on-board for review at a later time, or send emergency-related images in real time to security personnel; and
- Combine the health-monitoring capabilities of vital on-board components with AVL to send certain fault alarms in real time.

An example of components integrated through a common data network is shown in Figure 5-3. A complete review of the potential benefits offered by Information Level integration is provided in Chapter 7.

## OTHER DATA NETWORKS

Although Figure 5-3 uses J1708 as an example, a number of other data networks (open or proprietary) can be used to integrate components. Known data networks used in American and European transit bus applications are summarized below.

### CAN

The Controller Area Network (CAN) was originally developed and licensed by Robert Bosch GmbH for the European automotive market as a means of integrating electronic systems on automobiles. CAN has a fast response time and high reliability, making it suitable for demanding applications such as anti-lock brakes and air bags. The versatility of CAN has caused it to be adopted by other data networks as well. Examples include the DeviceNet systems manufactured by the 207 members of the Open DeviceNet Vendor Association (ODVA) (52). In fact, SAE's J1939 network is based in part on CAN.

Like SAE J1708, CAN provides a communication link between electronically controlled components using a serial data networking system. However, whereas the J1587 message-set extension of J1708 is based on an open protocol, each CAN implementation consists of a variety of message sets developed for specific applications. Although the term "CAN" is used uni-

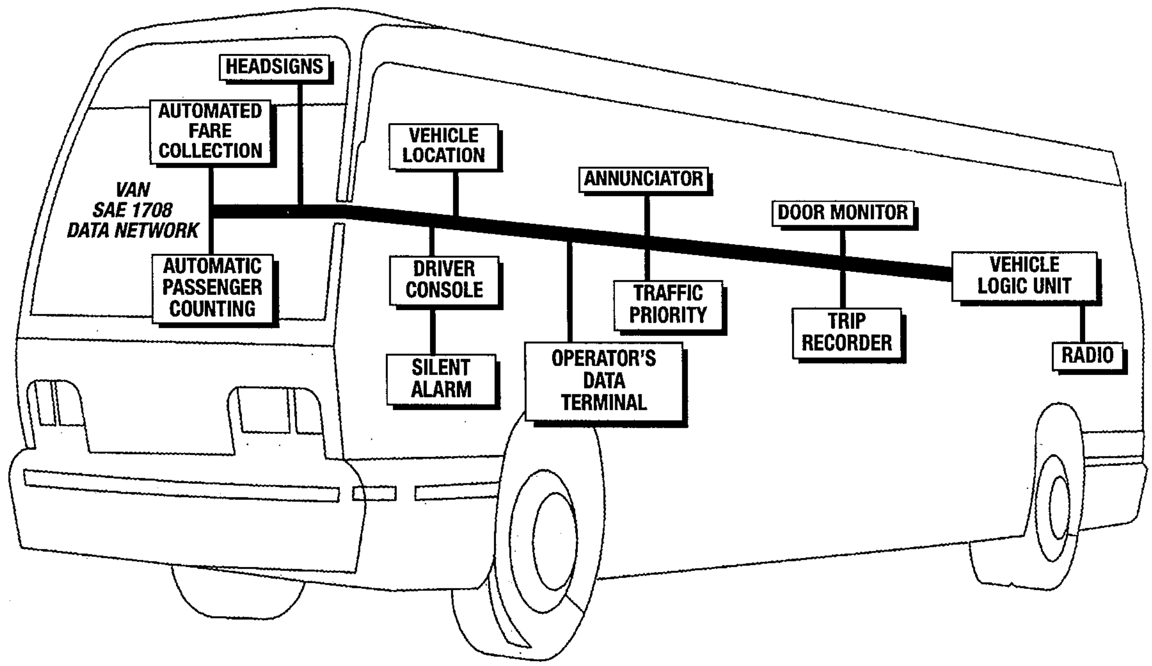


*Figure 5-3* *Information Level Integration designed around a J1708-based Vehicle Area Network.*

versally, several manufacturers produce different CAN products which cannot be interconnected.

Each CAN chip is a processor in its own right, installed within the electronic control module (ECM) of each device to help relieve the ECM of its communications processing duties. As a front-end processor, CAN is analogous to a secretary that sorts mail and screens telephone calls. The ability of CAN to relieve the ECM of duties is vital, especially as the number of messages transmitted per second on the network increases.

A portion of SAE's J1939 data network is based on the CAN protocol. As an advocate of open standards, SAE could not base its J1939 network on proprietary protocols. Instead, it has taken certain aspects of CAN and standardized applications for heavy-duty truck and bus use.

### *CAN Application to German Buses*

The German transit bus industry, organized under the Verband Deutscher Verkehrsunternehmen (VDV), is adopting different-speed versions of the CAN network for application to three bus levels (53). This three-tier approach is consistent with electronic integration in U.S. buses. The first level, called the "system bus," applies to engine management, braking, and other drivetrain-related functions. This level, which uses a fast-speed CAN for drivetrain integration, is capable of transmitting more than 125,000 bits per second.

The second "vehicle bus" level uses a slow-speed CAN network to handle basic on-off control functions of the electrical system (i.e., multiplexing). In the third CAN level, called the "information bus" (which refers to the integrated on-board information system or IBUS), VDV is pursuing the use of a slow-speed CAN network (53).

The VDV is also considering a separate slow-speed CAN protocol dedicated exclusively to the operator's workstation (54). Another option being considered by the VDV for the future is to combine the slower-speed CAN networks into a single network.

Concerning diagnostics on CAN, VDV has adopted an industrial standard known as "CAN in Automation" (CiA). This open standard allows components from different manufacturers to share the same diagnostic network (54).

### LonWorks

In addition to networks developed by SAE and CAN, there are several networks available on the market today that may have an influence in the future. One is LonWorks from the Echelon Corporation, used primarily for commercial building and industrial control markets (55). It is also used in rail car applications for electronically controlled pneumatic braking systems and automatic train controls. Some limited-production luxury motor coach manufacturers also use LonWorks to integrate the control of many on-board electrical and electronic amenities. The LonWorks protocol makes use of all seven layers of the OSI reference model, providing nearly complete flexibility in system integration. It uses a chip designed by Echelon and manufactured by Motorola and Toshiba.

### ITS Networks

SAE's Intelligent Transportation System (ITS) Division is developing an ITS Databus (i.e., data network) that can work in parallel with existing automotive electronics (56). SAE is also working on four ITS Safety and Human Factors projects (57).

Market costs, technology, business issues, service support, parts availability, and other issues will dictate whether on-board data networks such as CAN, LonWorks and others will become attractive enough to consider them for use in transit bus applications.

### NTCIP/TCIP

If ITS is to function as a truly integrated transportation system, all elements such as cars, buses, highways, and commercial vehicles must be able to exchange data in a similar fashion. However, it would be nearly impossible to require all ITS-related functions to use the same communication protocols and networks. Instead, the U.S. DOT is funding a project known as the National Transportation Communications for ITS Protocols (NTCIP).

NTCIP is not a data network like SAE J1708, J1939, CAN or LonWorks. Instead, NTCIP will provide a family of interfaces to serve as "connections" to the various data networks used in dissimilar transportation industries. The portion of the program responsible for developing data interfaces for public transportation is called the Transit Communications Interface Profiles (TCIP).

TCIP interfaces will allow transit agencies to collect on-board data over a network such as VAN/J1708 and convert them into a standard TCIP format. Data could then be exchanged with other departments within the agency that may store data in different formats. Data could also be exchanged with other ITS operating entities such as traffic management centers (58,59). Additional information on NTCIP, TCIP and VAN is provided in the following chapter.

## DATA NETWORK REVIEW

Transit buses currently apply data networks to three vehicle levels:

(1) Multiplexing in the Electrical Level to control discrete on/off type power control functions using proprietary communication protocols with transmission rates of about 38,000 to 57,000 bits/second;

(2) The Drivetrain Level, which integrates the engine, transmission, retarder, and brake systems using a combination of SAE networks, the J1708 family of networks with transmission rates of 9,600 bits/second, and the new J1939 network with a 250,000 bit rate; and

(3) The Information Level, which integrates AVL, fare collection, radio/communication, and other systems using either SAE J1708/1587, a proprietary communication network, or a combination of the two.

Despite the application to three distinct bus levels, each network does not function autonomously. Data between them can be exchanged through the use of a gateway, which further expands the integration process. A gateway is an electronic module that connects two data networks by converting the messages into the appropriate format. The sharing of data between the various bus levels provides increased functionality, allowing the bus to operate as an entire system.

TCIP is an example of a gateway technology, allowing on-board data to be transmitted to various ITS field locations in a standard format, thereby making bus transit part of a larger transportation system.

# PROGRAMS THAT SUPPORT ON-BOARD INTEGRATION

There are several programs funded by the U.S. DOT and others that support the integration of on-board electronics. This chapter reviews essential programs, including the Intelligent Transportation System (ITS), Advanced Public Transportation Systems (APTS), National Transportation Communications for ITS Protocols (NTCIP), Transit Communications Interface Profiles (TCIP), Vehicle Area Network (VAN), the Advanced Technology Transit Bus (ATTB), and the Demonstration of Universal Electric Transportation Subsystems (DUETS) Consortium. The top-down approach to this chapter begins with efforts to integrate ITS on a national level, and concludes with on-board VAN integration.

## SUMMARY

Previous chapters described how various data networks are applied to integrate on-board components in three bus levels. This chapter focuses on various programs that seek to standardize data formatting, including those relating to ITS activities and the integration of Information Level bus components. A standardized approach will eventually allow data to be exchanged in a uniform manner between each agency department, other transit agencies, and dissimilar elements of ITS.

The interoperability made possible through standardized data interfaces is essential to ITS. In fact, TEA 21, the reauthorization of the federal surface transportation program, contains language supporting standards development and ties federal funding for ITS projects to those standards. If ITS standards are not developed within a specified period, U.S. DOT could establish provisional standards.

The number of acronyms generated by programs that support the integration of advanced electronics can be overwhelming. To clarify them, ITS is the umbrella program that seeks to apply advanced electronic and communication technologies to all aspects of surface transportation

ITS is not responsible for producing individual technologies such as global positioning systems (GPS) and automatic vehicle location (AVL) — they existed before ITS was created. Instead, ITS seeks to network these technologies, allowing individual modes of transportation to function as an entire system. Of the six ITS-related transportation programs, the Advanced Public Transportation Systems (APTS) Program relates specifically to transit.

To facilitate ITS integration and establish a national architecture for data exchange, the National Transportation Communications for ITS Protocols (NTCIP) was established. Its mission is to develop standard communication interfaces. Interfaces would allow dissimilar elements of the ITS, each with its own communication protocol, to exchange data. Acting as an interpreter, NTCIP understands a given communication protocol and converts data into a format understood by all ITS participants.

Transit Communications Interface Profiles (TCIP) is the transit portion of the NTCIP program. TCIP ensures that data generated from transit vehicles and related agency operations are compatible with the NTCIP, and ultimately the entire ITS community.

The Vehicle Area Network (VAN) Program addresses component integration at the bus level. Using a modified version of SAE J1708 as a platform, VAN attempts to standardize the exchange of data between Information Level components such as AVL, APC, door systems, and other on-board electronics. VAN also ensures compatibility with the NTCIP/TCIP initiative, allowing on-board bus data to be exchanged with other ITS functions.

Figure 6-1 shows the organizational relationship between ITS and transit programs being developed to standardize interfaces for data exchange.

To help coordinate the various standards development efforts relating to transit, a committee within TCIP is beginning to lay the foundation for a Transit Standards Consortium. The Consortium plans to serve as a clearing house for transit standards currently being developed. Membership to the grass-roots, consensus-driven organization would be open to all public agencies, private companies and other interested parties.

This chapter also describes two additional electronics-related programs, both of which are administered by the FTA. One is the Advanced Technology Transit Bus (ATTB) Program. Among its many advanced features, ATTB incorporates an integrated electronic system. The other program is the Demonstration of Universal Electric Transportation

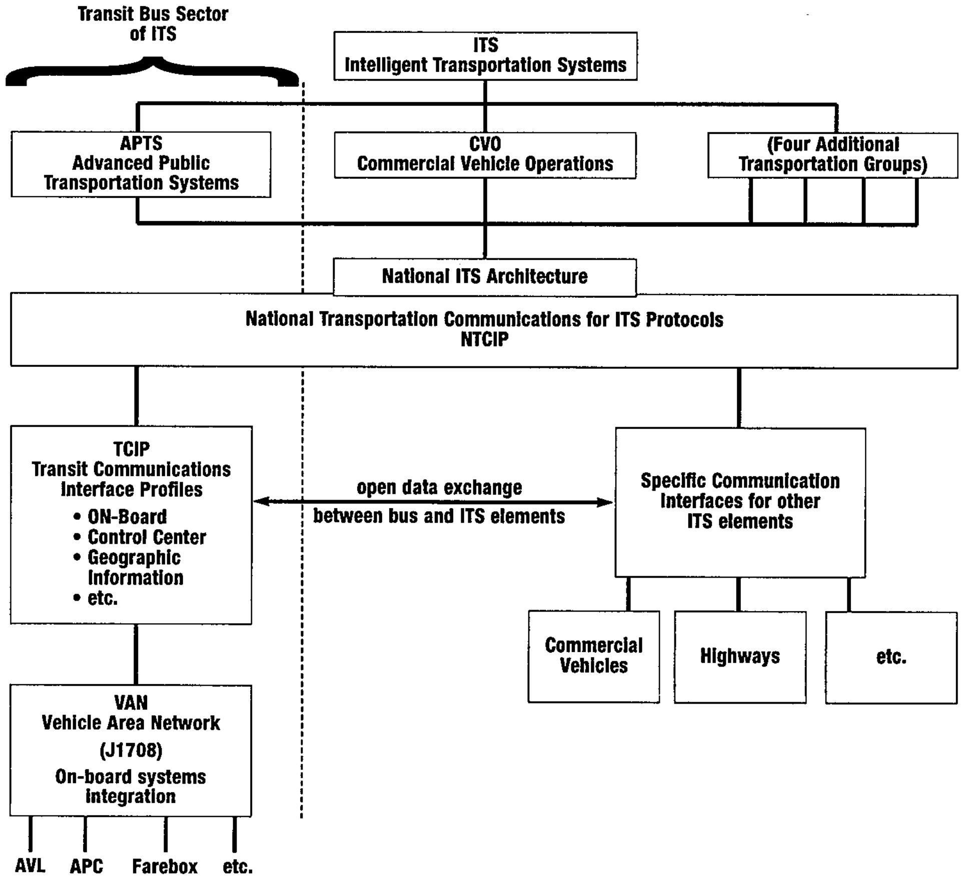


*Figure 6-1* *The organizational relationship between ITS and transit programs to standardize data exchange.*

Subsystems (DUETS) Consortium. The objectives of DUETS are to design and develop key enabling technologies for the next-generation, hybrid-electric transit bus.

## INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

### Overview

ITS offers alternative solutions to solving surface transportation problems. It applies current and emerging technologies that include information processing, communications, and electronics. Instead of each transportation mode acting independently, ITS plans to integrate them into a single system for improved efficiency, safety, and customer service.

The ITS program covers the gamut of transportation related functions from signal control and railroad grade crossings, to electronic fare collection, transit management, congestion reduction, security, emergency services, and others. The projects are intended to advance the state of technology, demonstrate public benefits, and foster cooperation between the public and private sectors. In other words, ITS intends to change how Americans travel.

### Background

The concept of ITS began during the 1960s, as large and small cities alike attempted to deal with increasing traffic congestion. In 1991, Congress, through the passage of the Intermodal Surface Transportation Efficiency Act (ISTEA), officially established ITS. Originally called the Intelligent Vehicle Highway Systems (IVHS), the name was changed to reflect the role that public transit would play in the program.

Reducing traffic congestion is a primary goal of ITS. During the past 20 years, the country's transportation system has struggled to keep pace with a growing population and its changing travel needs. According to one study, Americans lost more than two billion hours to traffic gridlock in 1996 (60). Congestion in metropolitan areas could worsen by 300 to 400 percent over the next 15 years unless significant changes are made. ITS intends to make those changes.

There are many publications that describe ITS and related programs in more detail. The "ITS Publications Catalog" contains a listing and description of major works on the subject (61).

### ITS America

The Intelligent Transportation Society of America, also known as ITS America, is a public-private organization established by Congress to coordinate the development and deployment of intelligent transportation systems in the United States. As a Federal Advisory Committee, ITS America counsels the U.S. DOT on ITS projects. Founded in 1991 as the Intelligent Vehicle Highway Society of America, it also changed its name in 1994 to reflect transit's participation.

ITS America's Advanced Public Transit Systems (APTS) Committee is responsible for shaping transit programs in the ITS transit arena. Through this committee, transit agencies can learn and share information about transit-related ITS technologies and projects. The American Public Transit Association (APTA) and ITS America formed a cooperative membership relationship in 1997, contributing articles and speakers to each other's publications and meetings.

### Joint Program Office (JPO) Established

Due to the many facets of ITS and the need for federal agency cooperation, the U.S. DOT established the Joint Program Office (JPO) to manage the ITS program in 1994. The JPO pools resources of DOT's modal administrations including the Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA), FTA, Federal Railroad Administration (FRA), and the Research and Special Programs Administration (RSPA). Under JPO's management, ITS is guided by four basic principals:

(1) Support research and development of ITS technologies to solve transportation problems.

(2) Ensure that newly developed ITS technologies are safe and cost effective.

(3) Promote and support the development of an interoperable and integrated system that reduces risks and costs to all users.

(4) Identify and emphasize private sector involvement.

### Examples of ITS Technologies

ITS encompasses many advanced technologies in an effort to solve transportation problems. The "Intelligent Transportation Systems (ITS) Projects Book," compiled by the U.S. DOT's JPO, describes the major ITS projects and technologies in nearly 400 pages of text (62). Some of the technologies being evaluated include: electronic communications, computer controlled highway systems, electronic traveler information systems, automatic passenger counters, GPS, video camera surveillance, AVL, collision avoidance/warning, automatic vehicle speed control, lane control/warning, electronic fare collection and integration, and other advanced systems.

### ITS Structure

The ITS program is subdivided into six major categories:

*Advanced Rural Transportation Systems (ARTS):* applies ITS technologies to address the unique safety and mobility problems of rural communities.

*Advanced Traveler Information Systems (ATIS):* technologies that disseminate information to assist travelers in moving from one location to another. Information dissemination mediums include the Internet, cable TV, telephone, and transportation kiosks.

*Advanced Transportation Management Systems (ATMS):* technologies that increase the efficiency of moving on-highway vehicles including advanced traffic signaling systems, electronic toll collection, dedicated freeway management, and ramp metering. A primary objective is to reduce accident response time and reroute traffic to reduce congestion and travel time.

*Advanced Vehicle Control Systems (AVCS):* technologies that allow the automated control of vehicles. Included are collision warning and avoidance systems, intelligent cruise control, lane control warning systems, drowsy driver detection, erratic steering wheel movement detection, and automated highway systems. AVCS also supports vision enhancement systems that can be useful in foggy weather conditions.

*Commercial Vehicle Operations (CVO):* technologies that improve commercial vehicle operations by monitoring vehicle location and providing operating status and schedule adherence. CVO provides vehicle tracking, electronic clearances at weigh stations and international boarder crossings, roadside safety inspections, automated milage/fuel reporting, and on-board safety monitoring.

*Advanced Public Transportation Systems (APTS):* application of technologies to improve public transportation. Technologies include AVL, APC, electronic destination signs and interior displays, and next-stop annunciators. Additional information on APTS technologies is provided later in this chapter.

Figure 6-2 illustrates how the six elements of ITS form a single transportation system.

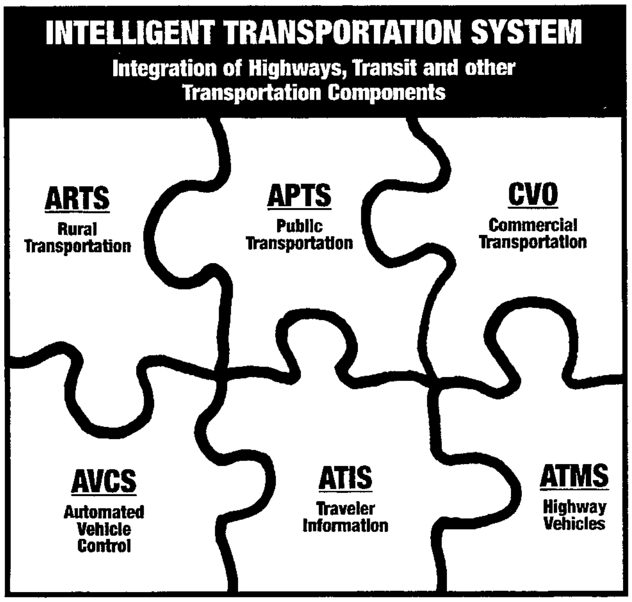


*Figure 6-2* *The six organizational elements of ITS.*

### Model Deployment Initiative (MDI)

To showcase the integration of major ITS technologies, the U.S. DOT has selected four areas — San Antonio, New York/New Jersey/Connecticut, Phoenix, and Seattle — to participate in a Model Deployment Initiative (MDI) Program. The $43 million program involves a 50-50 share between the federal government and a combination of local, state and private-sector partners. Each MDI site has a significant component of public transportation functions integrated with highway functions.

The program includes participation from various transportation and public safety agencies. The intent is to provide a coordinated transportation management approach to each of the four highly populated areas. An Operations Center collects and disseminates real-time information on traffic patterns and accidents. When an accident occurs, the Center notifies emergency response teams and other transportation providers to help mitigate the congestion. Information is also disseminated to the public via cable television and the Internet so alternative travel plans can be made. While en route, travelers can obtain information via electronic messages at transit centers and other terminals.

Model deployments are representative examples of what DOT hopes to achieve with ITS applications in cities throughout the country. While some MDI technologies are operational, others are in the developmental stage.

### National ITS Architecture

The need for a National ITS Architecture was identified in ISTEA and formally developed in 1996. It seeks to provide a model and framework for various transportation agencies to develop and implement ITS technologies that operate in unison. The MDI program described above is an example of such a model. Other objectives of the National ITS Architecture include:

- Develop a master plan that identifies the boundaries, participants, and strategies for developing an integrated, multimodal Intelligent Transportation System in a consistent manner throughout the U.S.; and to
- Serve as a resource for the development of specifications and standards for physical connections and data flows to allow all segments of the ITS community to use equipment and exchange data in a simpler, more cost effective manner.

The National Transportation Communications for ITS Protocols (NTCIP) is one of several standards-developing programs that will eventually allow all elements of ITS to function as an integrated system. Additional information on the NTCIP is provided below.

### TEA 21 Advances Standards

Reauthorization of the federal surface transportation program, known as the Transportation Equity Act for the 21st Century or "TEA 21," continues to emphasize the need for an ITS National Architecture and standards. In this regard, TEA 21 offers three general provisions (63):

(1) U.S. DOT is directed to develop, implement, and maintain a National Architecture and standards for ITS;

(2) The National Architecture shall promote ITS interoperability and efficiency; and

(3) Standards-setting organizations may be used as appropriate.

More significantly, TEA 21 requires additional actions to be taken to ensure the use of standards, and ties federal funding for ITS projects to adherence to those standards. By June 1, 1999, U.S. DOT must submit a report to Congress that identifies and gives the status of standards critical to ensuring national interoperability. If standards are not adopted by January 1, 2001, U.S. DOT can establish provisional standards. Before doing so, however, U.S. DOT must determine if the development of a standard jeopardizes the timely achievement of National Architecture goals. Under certain conditions, however, U.S. DOT can waive the provisional standards.

TEA 21 also states that all federal funds for ITS projects must conform to the National Architecture, along with all standards or provisional standards developed under ITS. Again, U.S. DOT is allowed to waive this requirement under certain conditions. Lastly, TEA 21 requires the FCC to allocate frequency spectrum for ITS purposes. FCC is directed to complete a rulemaking on this issue no later than January 1, 2000.

### ITS Education and Training

In 1996 the U.S. DOT issued the ITS Five-Year Strategic Plan, which includes a multifaceted training program being developed by FHWA, FTA, ITS America and its partners. The program includes seminars, workshops, short courses, technical assistance, and publications. The audience for ITS education and training includes U.S. DOT staff, elected officials, transportation service providers, and state, regional, and local managers.

Other training opportunities include the ITS Peer-to-Peer Program, which supports the deployment of ITS through a free technical assistance program. Sponsored by the FHWA and FTA, the program is available to the transportation community including state and local professionals, policy makers, planners, and other interested parties.

### Funding

ISTEA authorized a net total of $645 million for fiscal years 1992 to 1996. This amount was supplemented by $459 million in funds from the General Operating Expense budget. ISTEA also provided state and local governments with the flexibility to allocate funds as needed between transit and highway projects to solve transportation problems.

ISTEA expired in 1997. However, Congress found that ITS can mitigate surface transportation problems in a cost-effective manner, and that continued investments in ITS programs are warranted. As a result, TEA 21 reauthorizes the federal ITS program and provides overall funding of $1.28 billion from 1998 to 2003 (63). TEA 21 allocates spending across two broad categories: ITS standards, research and operational tests funded at $95 million to $110 million annually; and ITS deployment funded at $101 to $122 million annually.

### International ITS Programs

Europe and Japan have been actively pursuing the development and deployment of ITS technologies for several years. The counterpart to ITS America in Europe is called ERTICO, while the Asia-Pacific counterpart is called VERTIS.

### APTS

FTA's Advanced Public Transportation Systems (APTS) Program is an integral element of the ITS initiative. Through the APTS Program, FTA is making substantial investments in the deployment and evaluation of transit-related advanced technologies. The technologies are expected to reduce costs, and increase the utilization of people, facilities, and equipment.

The APTS Program involves the application and integration of technologies in four areas (64):

(1) Transit Management Systems;

(2) Automated Traveler Information Systems;

(3) Electronic Fare Payment Systems; and

(4) Transportation Demand Management.

Examples of the many APTS projects can be found in DOT's ITS Projects Book (62).

#### *Transit Management Systems*

This portion of APTS represents a broad range of bus and transit-center-based technologies to improve the overall planning, scheduling, and operations of transit systems. Technologies include AVL and related Geographic Information Systems (GIS), Computer Aided Dispatching (CAD), APC, transfer connection coordination, vehicle diagnostic systems, and other control technologies.

#### *Automated Traveler Information Systems*

This area involves several advanced computer and communication technologies designed to provide transit riders with real-time, pre-trip and en-route information. The information allows riders to make informed decisions regarding their mode of travel, routes, and travel time. Technologies include in-terminal and in-vehicle information annunciators and displays, along with remote information systems such as kiosks, telephone systems, cable and interactive TV, and the Internet.

*Electronic Fare Payment Systems*

This portion of APTS includes advanced fare collection and fare media technologies designed to make fare payment more convenient for passengers, and fare collection more efficient and flexible for transit agencies. Technologies include automated fare payment and multi-operator integrated fare systems. Also included are fare media alternatives such as magnetic stripe and smart cards, along with associated fare collection and processing systems. Technologies are intended to increase fare collection throughput, reduce pilferage, and reduce maintenance and money handling costs.

*Transportation Demand Management*

The final APTS category includes technologies that improve the efficiency of paratransit services to accommodate increased ridership resulting from ITS. Applications include computerized demand responsive transit reservation and dispatching systems, strategies to promote ride sharing, and coordinated transportation services among transit and non-transit providers.

### NTCIP

The development of standards is critical to allow the many elements of ITS to exchange data in an orderly fashion. The National Transportation Communications for ITS Protocols (NTCIP) is the overall program responsible for developing these standards. When fully implemented, the standards will allow all elements of ITS — commercial transportation, traffic control, rural transportation, public transportation, and others — to exchange data and operate as an integrated transportation system.

The ability to share data in a standard format is important because the various elements of ITS are typically operated by separate organizations, each with its own equipment and data needs. Although NTCIP allows each transportation mode to have its own communication protocol, the protocols must be compatible with NTCIP. An analogy would be the Internet where owners of IBM and Apple computers can access identical information through computers or suitable clones that use different operating systems.

NTCIP is funded by the U.S. DOT's Joint Program Office for ITS. The contractor is a consortium of standards-development organizations. A guide available from NTCIP describes the program in greater detail (65).

### TCIP

Transit Communications Interface Profiles (TCIP) is the program responsible for ensuring the compatibility of transit-related data with NTCIP, and ultimately the entire ITS community. TCIP is funded by the U.S. DOT's Joint Program Office as an extension of the NTCIP project.

The Institute of Transportation Engineers is under contract with the JPO to create TCIP standards. Hundreds of transit volunteers assist with developing a family of standards being created under seven technical working groups. The groups are addressing data definitions and message sets for the control center, on-board bus components, passenger information, scheduling, runcutting, spatial representations, and traffic management. The first set of final standards are expected to be released by the end of 1998. Tests will then be required to actually prove the standards in a transit application.

Unlike SAE J1708, TCIP is not a communications protocol. In fact, the "P" in TCIP was changed from "Protocols" to "Profiles." The change more accurately reflects the purpose of the program, which is to develop standard interfaces that will allow several communication protocols, such as SAE J1708, to exchange data in a standard format. As a result, transit agency departments that format data in several ways will be able to share data in a uniform manner — so will transit agencies and other ITS elements.

Figure 6-3 shows how on-board data formatted into the TCIP interface would be transmitted back to the agency and to other elements of the ITS community when the standards are in place. As Figure 6-3 illustrates, TCIP will allow agencies to continue to use proprietary-based radio communication systems. As long as data are converted to a TCIP-compatible format, the radio system can use its own protocol to transmit data to and from the bus.

In addition to real-time applications, data could be transferred to and from the bus via floppy disks or other means. Additional information on procedures to transfer data is provided in Chapter 7.

### Consortium Furthers Need for Standards

As TCIP continued its work to develop data interfaces, other issues arose. For one, TCIP is only responsible for a limited set of transit-related ITS activities. It does not address standards for communications, wiring, testing, and other areas where standards could be beneficial. In fact, there is no forum for addressing these issues, much less a mechanism for funding them. Additionally, consensus-driven standards such as the "White Book" revision, the SAE J1708 VAN Program,

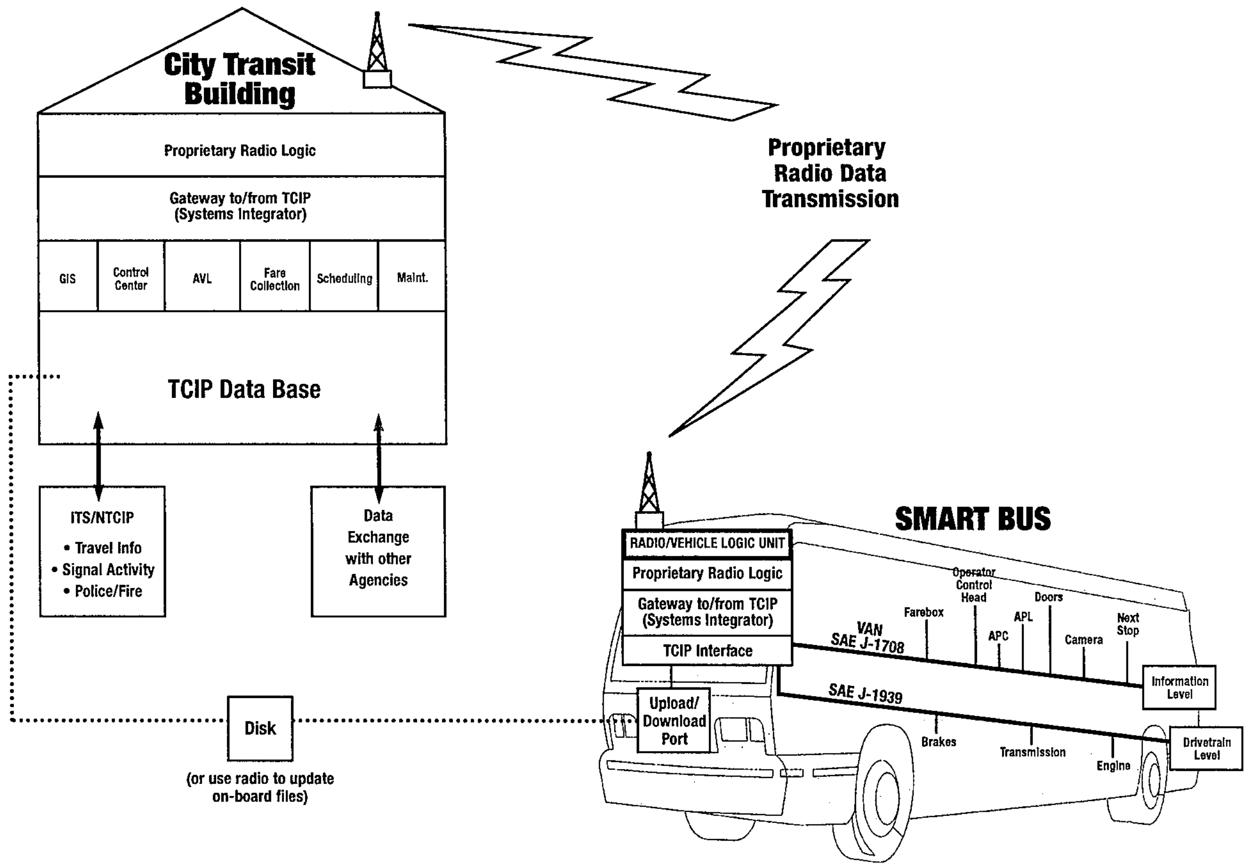


*Figure 6-3* *Conceptual illustration of how a bus and central control would convert data into a TCIP format for exchange using a proprietary radio system.*

and TCIP were developed in relative isolation from one another.

To help move the concept of an industry-based policy forum forward, the TCIP Steering Committee began to lay the foundation for a Transit Standards Consortium. Details on the Consortium's exact role and organization structure are still being worked out.

Based on available material, the Consortium would act as a clearing house for transit standards currently being developed (66, 67, 68). Its mission would be to provide a facilitating mechanism for the development and implementation of standards including testing and professional capacity-building.

The consortium is intended to be a grass-roots, consensus-driven organization. Membership would be open to all public agencies, private companies, and other interested parties. It would be governed by a Board of Directors, while day-to-day activities would be handled by an executive director and a small support staff. Specific transit standards projects would be proposed by technical committees of the Consortium and funded by member dues and other contributions.

The proposed Consortium has the potential to address the overall needs of transit concerning the formation of standards relating to ITS activities, on-board electronic integration, communication, and other areas where standards would be beneficial.

## VEHICLE AREA NETWORK (VAN)

### Overview

The vehicle area network (VAN) is next on the chain of data communication standards. While NTCIP addresses the overall ITS infrastructure and TCIP deals with transit operations, VAN addresses the flow of data within the bus itself. The implication is that data produced from the bus is compatible with TCIP, which in turn is compatible with NTCIP and the overall ITS architecture. Compatibility with TCIP allows the bus to use an on-board data network that suits transit's needs. Like the TCIP program, VAN is in the development stage and has not been formally adopted or fully tested by bus transit.

### Background

As Information Level components were added to buses, it became clear that integrating the devices could provide greater functions and benefits. In addition to improving customer service, the integration could also assist ITS efforts to improve the efficiency of transportation as a whole. The challenge, however, was to integrate an assortment of devices from different manufacturers as a complete on-board system that would work in unison.

One approach is to allow propriety networks, which makes the integrator the only source for extra devices or enhancements. However, when issues arose over sole-source procurements and the possibility of proprietary suppliers going out of business, the FTA responded.

Acting as the lead agency in the ITS effort for APTS, the FTA created a vehicle area network (VAN) Subcommittee to study and recommend a solution to the problem of integrating on-board electronic components, functions, and communication interfaces (69). The Subcommittee is part of the APTS Technical Standards Task Force, consisting of representatives from transit agencies, system integrators, component suppliers, academia, consultants, ITS America, APTA, and the Canadian Ministry of Transportation.

### Objectives

The VAN Subcommittee set out to recommend a solution to on-board integration with the following guidelines:

- Minimize hardware cost and overhead;
- Provide interchangeable components and open standards, while allowing original equipment manufacturers (OEMs) to retain certain proprietary considerations to customize their products; and
- Provide flexibility for expansion and technology advancements with minimum impact on hardware and software.

The VAN Subcommittee considered several on-board Information Level components. It also considered several data networks, including proprietary ones, in an effort to identify the most efficient, reliable and cost effective solution to on-board integration.

### SAE J1708 Recommended

In the final analysis, VAN recommended SAE's existing J1708 data network as a basis for standardized on-board integration. Revised for transit bus applications, the standard is referred to as SAE J1708T — the "T" denoting transit. The J1708 network is already applied to transit buses, and would only require some transit-specific additions to make it adaptable to Information Level integration. Once approved by the ITS/APTS Technical Standards Task Force, a request was formally made to SAE to include the transit-specific features to its existing standard. The January 1994 release of the SAE J1708/1587 documents contains these transit-specific standards.

VAN is also recommending conformance to the J1455 document entitled "Joint SAE/TMC Recommended Environmental Practices for Electrical System Design." As described in Chapter 5, SAE J1455 ensures that electrical equipment designs will endure the unique operating environment of a heavy-duty vehicle. It defines expected conditions of vibration, temperature, and other environmental and durability issues.

Besides the requirements of J1708 and J1455, work is underway to add a standard for a VAN-specific cable and connector. In addition to the existing pair of twisted wires required to transmit data, the new cable and connector standard includes provisions for supplying "clean" power from the vehicle's battery. Figure 6-4 shows the four SAE standards that make up the VAN network.

The need for a new cable/connector standard that also incorporates a power supply stems from a need to further streamline bus wiring and provide "clean" power to processor-controlled electronic devices. Power for on-board components is currently supplied separately through traditional "hard" wiring or a multiplexed approach. Although multiplexing reduces wiring, further reductions are possible by supplying components linked to the J1708/VAN network with a power and data link through one cable. Doing so eliminates redundant wiring harnesses and connectors. It also eliminates the need to have separate power conditioning equipment to provide a constant 12 or 24 volt supply of clean power to sensitive electronic equipment.

By adopting a modular "extension cord" approach, the cables can be separated for replacement or fault isolation. Outlet boxes located along the cable allow devices to be plugged in, similar to the way appliances are "connected" in a home electrical system. However, since the new VAN standard also includes a data link, a true analogy would be a home telephone that uses only one plug connection for both power and communication services. Figure 6-5 shows how devices are connected to the network using separate power and data cables. Figure 6-6 shows the same approach using a single cable to supply both power and data.

### VAN Benefits

The benefits offered by a vehicle area network that standardizes on-board data communications and hardware interfaces include:

- Transit agencies can purchase components on a competitive basis from several suppliers, knowing they can be installed in their buses in a "plug and play" fashion; "
- Agencies can "assemble" an on-board system based on their needs by selecting only those components that they feel will bring the greatest benefits;
- Manufacturers can compete on performance benefits alone such as speed, accuracy, and power demands. They no longer have to build, stock and support a variety of custom products developed and paid for by various agency procurements;
- The modular approach to component integration allows agencies to expand on-board systems without discarding previous investments;
- The entire system becomes transparent to the vehicle on which it is installed; and
- The standardized solution to data communications and interfaces is transportable to bus, paratransit, and other transit vehicles.

### VAN Transmission Speed

The speed of SAE J1708 and its ability to handle Information Level integration is being questioned. A major issue centers around data throughput — or how many data characters can be moved from one location to another in a fixed amount of time. Some claim that the 9600 baud rate of J1708 is too slow. Proponents claim that it is fast enough, and increasing speed would only add unnecessary costs. The main point that proponents make is that on-board data transmission must be considered separately from vehicle-to-agency data transmission.

In the case of on-board data transmission, devices connected to the network must have enough speed to transmit data to the VLU, which serves as the on-board central processor. Depending on the function, the VLU could process the data immediately (i.e., use vehicle location data to trigger a next-stop announcement), or store data for historical purposes (i.e., analyze farebox and location data at a later time to determine ridership trends).

According to calculations made by the VAN Committee, the 9600 baud rate of J1708 can generate about 44,000 characters per minute (70). Reportedly, this rate is sufficient to process on-board data for immediate use and to store historical data for future reference. The Committee also claims that the number of J1708 installations in the field has not identified any insufficient areas of the standard in real-world applications.

Others claim that if J1708T was faster, more on-board data could be available at the transit agency in real or near-real time. However, in the case of getting data from the vehicle to the transit agency, speed is not a function of the on-board J1708 network. Instead, speed is a function of the VLU's communications interfaces such as those provided by the radio, optic links, and direct cable connections. The discussion

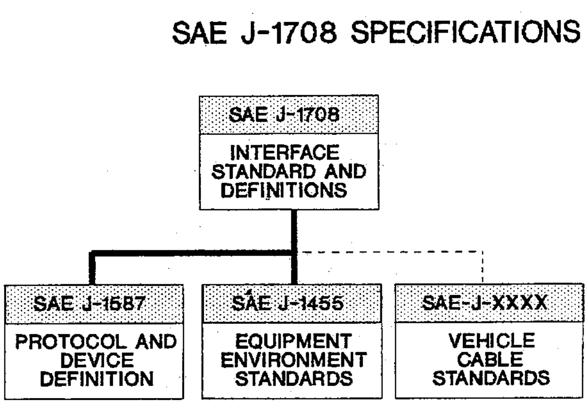


*Figure 6-4* ***Four SAE standards required for the VAN network.***
*(Courtesy of VAN Subcommittee)*

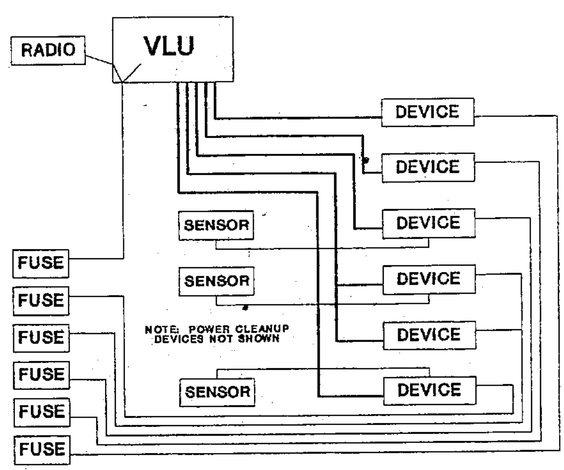


*Figure 6-5* ***Devices connected on a network with separate power and data cables.***
*(Courtesy of VAN Subcommittee)*

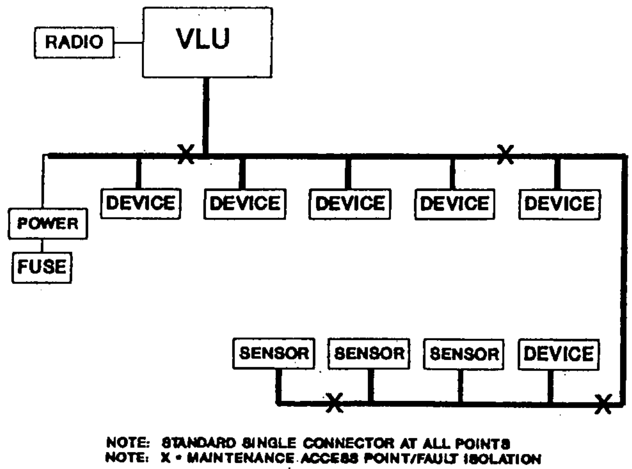


*Figure 6-6* ***Devices connected on a network with a single data and power cable.*** *(Courtesy of VAN Subcommittee)*

below is based on using the radio to transmit data in real time.

While J1708T has a 9600 baud rate, most radio systems have a baud rate of only 4800 bits per second. Since data is organized into eight bit "bytes," the 4800 rate is divided by eight, to produce 600 data characters per second. Due to other factors such as forward error correction, radio turn on/off times, and vehicle addressing data requirements, the net rate drops to about 300 characters per second. When allowing 30 seconds per minute for other radio traffic, the number of data characters transmitted per minute becomes 9000 (30 seconds x 300 data characters per second) (70).

Compared to J1708's rate of about 44,000 characters per minute, the radio's 9000 character rate becomes the limiting factor when looking at data transmission between the bus and transit agency. Given the radio's limitations, real-time data needs must be prioritized. In the case of vehicle location, real-time data is important to provide accurate traveler information. Real-time engine alarms may also be important to some agencies. However, the speed of other data may not be so critical. For example, farebox and APC data are not required immediately and can be analyzed after the bus returns from service. Updates to on-board bus files (i.e., destinations and schedules) could be performed during idle radio time during the day, or at night when radio use is diminished.

Regardless of how quickly data is required, the onboard data network of J1708 is not considered to be the limiting factor. To put this issue in perspective, a one megabyte file from the transit agency to the bus requires about 111 minutes of radio air time. Once onboard the vehicle, however, the same file can be transported by J1708 to a device in about 22 seconds (70).

Examples of transmitting data between the bus and transit agency provided here are based on radio use. As noted earlier, the transfer of data could also occur through diskettes, wireless technologies, and other methods.

Issues surrounding J1708, especially data speed, must be resolved before the transit industry can adopt any standard. Until then, agencies will continue to take delivery of systems that integrate AVL, APC, fareboxes, destination signs, and other components using a "hodgepodge" of communication protocols.

## ADVANCED TECHNOLOGY TRANSIT BUS (ATTB)

### Background/Overview

The need for low cost, low emissions, reliable and safe transit buses was growing during the late 1980s. To address these needs, a national effort to design a transit bus that used off-the-shelf technologies from the aerospace and automotive industries led to the Advanced Technology Transit Bus (ATTB) program (71).

The ATTB program began in 1992 with the overall objective to design, manufacture, and demonstrate a 40-foot heavy-duty transit bus from a "clean sheet of paper." Partners in the program include the FTA, the Los Angeles County Metropolitan Transportation Authority (LACMTA), Metropolitan Transportation Authority of Harris County, Texas (METRO) and Northrop Grumman as the primary contractor. The total ATTB program cost is $56.9 million, which includes $11.4 million from MTA and METRO.

Six prototypes have been manufactured and will complete field testing by the end of 1998. A Rapid Transit Review Board, consisting of 20 transit agency representatives, has participated throughout the program's conceptual design, technology validation, and prototype manufacturing phases.

### Key Features and Benefits

Key features and benefits expected from the ATTB program include:

- Low, flat floor throughout the bus.
- Primary structure consisting of closed-cell foam cores sandwiched between fiberglass skins for ease of repair, extended durability, and reduced weight.

- A propulsion system that uses wheel motors driven by an electrical generator and a compressed natural gas (CNG) engine.
- Ability to accommodate future powerplants using advanced fuel cell or other zero emission technology.
- Allow for an energy storage device (i.e., flywheel or ultracapacitor) that would recapture braking energy through wheel motor regeneration.
- An ergonomically designed operator workstation.
- An advanced vehicle management computer (VMC) that provides overall control of the ATTB including power and signal management.

### Electrical System

The ATTB electrical system distributes power to ensure operation of all electrical components. In addition to primary power distribution, the system consists of overload protection and electric drive power distribution. Important design features to improve reliability and maintainability include:

- Integrated diagnostics for certain sub-systems;
- Accessible wire routing (i.e., overhead for easy reach);
- Use of solid state relays;
- Use of reliable sensors and avoidance of multi-connectors; and
- Reduced need for extra test equipment for diagnostics and trouble shooting.

The ATTB features a modular system design that allows each major component, panel or wire bundle to be easily maintained and replaced with standard hand tools. Ease of accessibility was accomplished by the concurrent engineering design approach.

Electronic signals in the ATTB are transmitted through individual wires, much like traditional wiring systems. The result is an extremely cumbersome wire routing. To keep costs low, ATTB prototypes do not include electrical system multiplexing. However, should the ATTB go into production, it will be specified with such a system.

### Vehicle Management Computer

The ATTB Vehicle Management Computer (VMC) provides overall vehicle control and management, and is the outcome of extensive systems integration efforts. In general, the VMC manages the health of the electrical systems. A custom designed VMC was developed by Northrop Grumman for the ATTB prototypes.

In addition to power distribution and management, there are two main functions of the VMC. The first is to monitor data signals from system components to ensure a safe operational state. The second is to send caution, advisory, and warning signals. A caution signal will indicate that a set parameter has been exceeded, but is not serious enough to warrant action by the driver or maintenance personnel. Advisory signals must be reported and addressed, but a root cause is not always apparent.

A warning signal is the most serious, sending an alarm to the operator to pull over immediately. In serious situations, the bus system may shut down immediately. Warning signals include major system faults such as engine oil temperature and pressure, lights, doors, brakes, etc. Warning signals for major systems are viewed in the operator's workstation.

Since many components are not yet designed with remote terminals (RTs), the signals must be conditioned or they cannot be read by the VMC. In this case, the ATTB uses its own sensors to monitor conditions and send warning signals.

The ATTB allows for real-time display of appropriate signals so the operator or technician can observe operational conditions. For signals that do not need real-time observation, data review may be conducted using a laptop interface with the VMC. The intent of real-time monitoring is to improve service reliability by predicting failures in advance.

### DUETS CONSORTIUM

The Demonstration of Universal Electric Transportation Subsystems, known as the DUETS Consortium, is a $8.3 million technology reinvestment program administered by FTA (72). The objective of the program is to demonstrate four major bus electronic subsystem technologies:

(1) Hybrid electric drivetrain consisting of internal- combustion engine, generator set, battery pack, and electric drive motor(s);

(2) Integrated vehicle management system (VMS) with a high-speed fiber optic data network;

(3) Advanced semi-active rear suspension to improve ride characteristics, and provide a lower floor due to reduced suspension travel and wheel housing height requirements; and

(4) Regenerative braking, which converts mechanical energy into electrical energy for battery pack storage.

The DUETS Consortium includes Kaman Electromagnetics Corporation, Honeywell Technology Center, Davis Technologies International, and NovaBUS. Sandia National Laboratories is also a participant in the program and will perform bus testing. The current project effort includes testing, data collection, and evaluation of all subsystems.

Originally, the hybrid-electric propulsion system consisted of a CNG engine, nickel-cadmium batteries, and separate wheel motors. The new configuration will include a diesel hybrid-electric system utilizing lead-acid batteries and a single traction motor powering a standard V-drive bus axle. Once complete, extensive testing of all systems will be conducted to evaluate the durability of drive components and power control equipment, and to determine the extent of electromagnetic radiation.

### Vehicle Management System

Of particular interest to this study is DUETS' Vehicle Management System (VMS) consisting of eight nodes (i.e., modules) strategically located throughout the bus and connected by a high-speed fiber optic data network. All devices and sensors connected to the network are linked through the individual nodes, not by connecting devices to the fiber-optic cable itself.

Developed for aircraft, the VMS handles all onboard data communication and control functions. Included are standard bus functions such as interior and exterior lighting, doors, kneeling, HVAC, and others. VMS senses a variety of bus conditions including those initiated by the operator's switch panels, door and kneeling status, and passenger requests. The VMS also controls the semi-active suspension system and manages control over the hybrid electric propulsion system.

Status of all activities taking place on the network is stored in memory for future analysis by maintenance and other agency personnel.

# POTENTIAL BENEFITS OF ON-BOARD INTEGRATION

This chapter summarizes the potential benefits of on-board electronic integration as viewed from maintenance, service line, and bus operation perspectives. The primary focus is on Information Level integration because benefits offered by multiplexing and drivetrain integration have been examined in earlier chapters.

The material presented here depicts a "best case" scenario of what agencies can hope to achieve from the integration under ideal conditions based on available technologies. Achieving this ideal scenario assumes that:

(1) A data network is in place that ensures complete interoperability between devices, and allows them to be easily upgraded and expanded;

(2) The functionality of each component and the results expected from them are clearly specified by the transit agency;

(3) The equipment and software as delivered perform as promised by the vendor;

(4) Agencies have the resources to operate and maintain the equipment properly, and can manage all of the data produced from it; and

(5) Agencies have the capability to take full advantage of the technology. For example, AVL can inform a dispatcher that buses are bunched on a particular route. However, if steps are not taken to mobilize buses, that particular benefit lies dormant.

## SUMMARY

As described in Chapter 2, electronics has enhanced the functionality of individual bus components such as engines, transmissions, fareboxes, door controls and others. Integrating components through data networks enables them to collectively provide benefits that no single component could accomplish individually.

Benefits provided by some applications are more tangible than others. For example, in the first stage of electronic application, where simple features such as transistors are added to improve individual components, the benefits are very real. Solid state radios, fluorescent lighting, and battery charging systems have provided obvious benefits to all forms of transportation, including buses.

In the second stage of electronic application where electronic control modules (ECMs) exert greater control over a component, the benefits are also apparent. For example, meeting exhaust emission regulations — diesel or gasoline — would not be possible without electronically-controlled engines.

In the third stage of electronic application where on-board electronics are integrated into larger systems, the benefits can be greater. Again, some are easier to substantiate than others. Benefits provided by multiplexing and drivetrain integration are straightforward. In addition to being more mature, the integrations were developed and proven by larger industries before being transferred to buses as a secondary user.

Electrical system multiplexing, for instance, has proven itself in assembly-line automation and aerospace industries. As a direct replacement for relay-logic-based electrical systems, multiplexing is easily transferrable to buses as a complete system — installed and tested by the bus builder prior to delivery. Benefits derived from multiplexing include improved diagnostics, reduced wiring complexity, ease of adding features through software changes, and reduced electrical system complexity.

As another mature technology, drivetrain integration has also provided tangible benefits. Integration is based on data networks developed specifically for heavy-duty truck and bus applications by the SAE. Like multiplexing, integration is accomplished by the bus builder and delivered to the end user as an integral system. Benefits derived from drivetrain integration include improved driveability, fuel economy, and diagnostics. Another obvious benefit involves the creation of two safety features: anti-lock brakes and traction control, both of which would not be possible without electronic integration.

Although the potential exists, benefits derived from Information Level integration are more difficult to quantify for several reasons. The integration is relatively new to transit, built primarily around proprietary data communication networks and interfaces that make it difficult to add new functions or modify existing ones. Unlike multiplexing and drivetrain components, Information Level integration is not typically accomplished by the bus builder. System integrators, those specializing in the integration, tend to be new to transit and

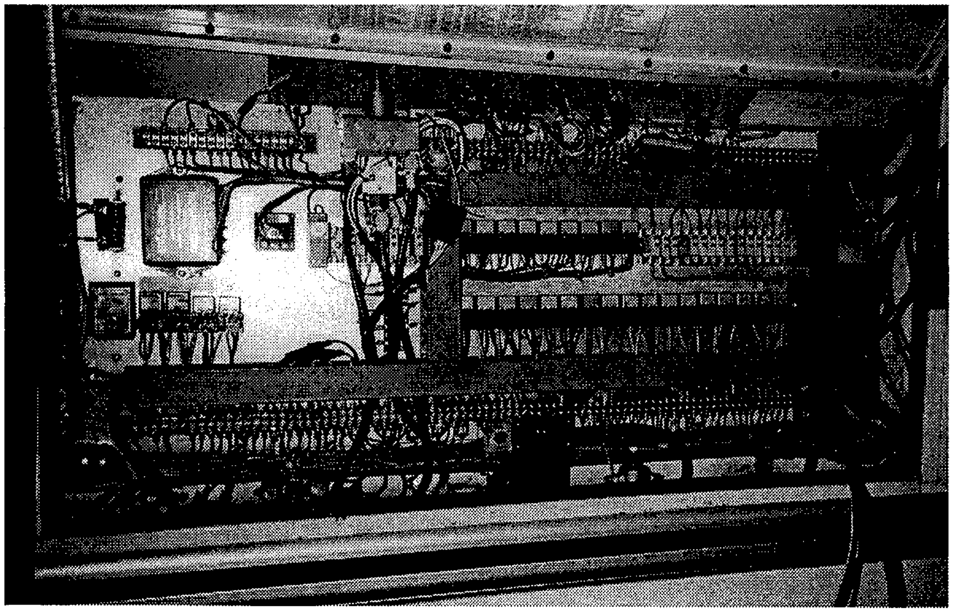

*Figure 7-1* *Relay-logic-based bus electrical system.*

may not fully understand its needs. Conversely, many transit agencies are struggling to understand how the new technology can help solve problems.

Furthermore, the application of fare collection, stop annunciators, and passenger counters are unique to transit. Integration of unique functions does not allow transit to transfer the technology and experiences from a larger industry, as was the case with multiplexing and drivetrain integration.

Despite the obstacles inherent with any emerging technology, Information Level integration has the potential to provide many benefits to agencies and their customers. Advanced radio systems with data capabilities can improve the communications between the operator and dispatcher. Radios integrated with AVL and other systems provide agencies with bus location information, make use of silent alarms and covert microphones, and allow dispatchers to make announcements in specific buses. AVL integrated with fareboxes, APC, and other systems provides a more accurate indication of passenger boardings at specific locations.

Additionally, the integration of AVL, radios, and other equipment allows time- and location-stamps to be placed on each bus activity. Stored onboard or transmitted in real time, the concept of time- and location-stamped data has the potential to document a large array of agency- and vehicle-based performance indicators.

## ELECTRICAL SYSTEM MULTIPLEXING

Multiplexing was a logical replacement for traditional electrical systems, which had become very complex and prone to failures. Today, most new buses feature it as standard equipment. Although some system components are more expensive, multiplexing is offered by bus manufacturers at prices similar to conventional systems because of savings that result from installation, engineering, and testing. Multiplexing also reduces the number of relays, connectors, and weight associated with those components. Figure 7-1 shows the complexity of a relay-logic-based electrical system, while Figure 7-2 shows a more simplified and orderly multiplexed system.

Bus maintenance receives the majority of the benefits derived from electrical system multiplexing. Although the theory of operation can be difficult to comprehend, multiplexing performs relatively basic functions. Once the concept is understood, working with it is easier than traditional electrical systems. In a multiplexed system the flow of electrical current throughout the bus is denoted visually through LED lamps, which are also labeled to identify each circuit. This greatly simplifies the troubleshooting of electrical system faults.

Benefits to bus operations are somewhat limited. However, changes to the electrical system to satisfy passenger, operator and safety needs can be made easily through software changes instead of running new wires and relays. Examples include the addition of daytime headlamps, automatically activating the headlamps when the wipers are engaged to satisfy State regulations, adding lamps to improve visibility, and adding door interlock functions to improve passenger safety. Although similar modifications can be made with a

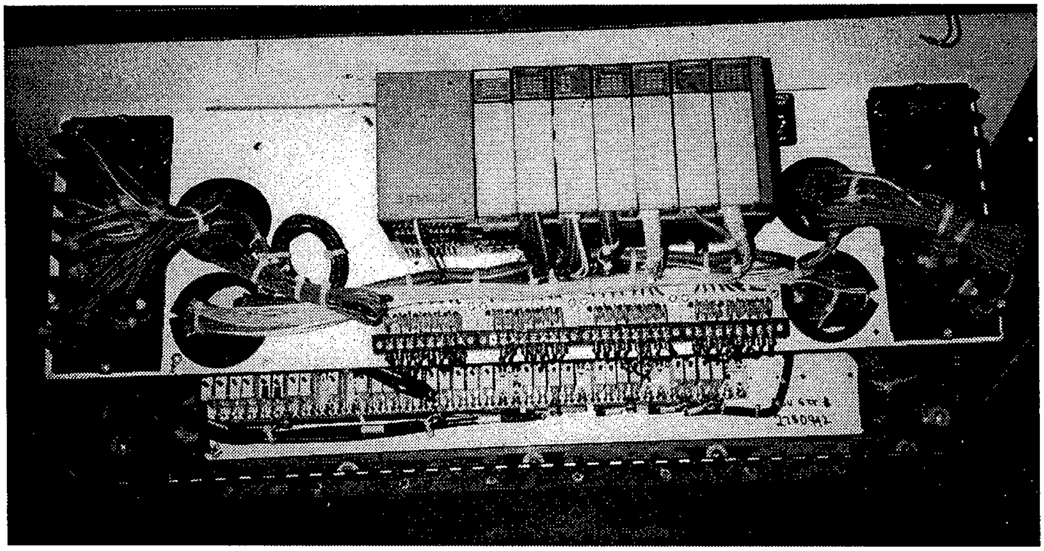

*Figure 7-2 Multiplexed electrical system with main controller and I/O modules stacked together.*

hard-wired approach, the changes are much easier with multiplexing since they are implemented through software changes using existing circuitry.

To service line personnel, the operation of multiplexing is completely invisible. However, if "running repairs" to the electrical system are required, they can be diagnosed quickly. Additionally, the monitoring capabilities of multiplexing can be configured to inform the operator and service personnel of malfunctioning equipment such as lights and other electrical devices.

## DRIVETRAIN INTEGRATION

The integration of drivetrain components provides several benefits. Instead of the engine ECM being programmed to perform tasks based on engine conditions alone, the control algorithm (i.e., pre-programmed logic) takes into account data supplied by other components. For example, when the transmission is prepared to make a gear change, the engine momentarily reduces its torque to provide a smoother shift to improve passenger comfort.

Other benefits made possible by drivetrain integration include the creation of anti-lock braking (ABS) and automatic traction control (ATC) — significant safety features that would not be possible without a formalized network of data exchange.

When the ABS/ATC system detects that a particular tire has lost grip with the road surface, the control modules take into account engine speed and torque, brake pedal force, accelerator position, transmission gear range, and retarder application before applying or releasing air pressure to a given wheel brake. Based on the algorithm, the control module can disable a gear change, torque converter lockup clutch, or retarder function, and request that the transmission be placed in neutral. These actions ensure that measures taken to prevent wheel lockup and loss of traction and vehicle control are accomplished effectively with data provided from several components.

### Maintenance Benefits

In addition to processing data quickly, electronically-controlled drivetrain components can store data for future analysis by maintenance personnel. Critical failures are communicated directly to the operator via visual and/or audible alarms. Depending on the fault, the component can limit its performance to prevent additional damage (i.e., automatically place itself in a "limp home" mode). To obtain fault codes, technicians connect a diagnostic tool that helps locate the fault and facilitate repairs. Besides offering fault codes, data stored in drivetrain ECMs can be downloaded and reviewed as a way of identifying imminent failures, or to analyze operator and component performance.

Since the engine ECM is linked to other components, it stores data collected from several sources. Many agencies are unaware of the vast amount of data that exists in the engine ECM. Much of it, however, is only available by purchasing special software programs. A typical engine software program can provide maintenance managers with:

- Maximum bus speed attained at specified intervals.
- Maximum engine RPM attained at specified intervals.

- Engine idle time based on various conditions such as low battery and low temperature.
- Ratio of idle time to total operating time.
- Maximum coolant temperature over time.
- Maximum oil temperature over time.
- Engine hours based on various speed bands (i.e., 0-9 mph, 10-19 mph, etc.).
- Vehicle miles traveled for a given time period.
- Fuel economy (in miles per gallon) segmented by engine hours and days.
- Excessive braking applications.
- Amount of time spent in each drive gear.
- Engine usage profile showing each day of the month and how much time was spent operating, idling, and inactive.

In addition to using the engine as a collection point for data, drivetrain components can be linked to an event data recorder or the VLU of an AVL system. Both can serve to collect and disseminate drivetrain data. Integration with the radio allows key drivetrain functions to be sent to the transit agency in real time.

### Service Line Benefits

The service line, where buses return daily to be fueled, cleaned and inspected for mechanical defects, can also benefit from drivetrain integration. Entering daily mileage, inspecting fluid levels, and performing mechanical inspections — all of which are performed manually by many agencies — can be accomplished with a combination of on-board and off-board electronics. The application of electronic technologies reduces the data entry errors normally associated with manual recordings and inspections.

#### *Recording Bus Number and Mileage Traveled*

An electronic hubodometer, mounted to the curbside rear wheel, automatically counts and records wheel revolutions. When it receives a radio frequency (RF) signal from either a hand-held device or fixed-mount receiver on the service line, the electronic hubodometer transmits the preprogrammed bus number, life-to-date mileage, and status of the battery powering the unit.

Data from the electronic hubodometer can then be downloaded to a central computer where mileage reports are generated. Hubodometer data can also be integrated with a fluid management system to provide managers with data on fuel and fluid consumption based on total miles traveled. Since the bus number and fuel/fluid consumption are logged electronically, human errors caused by transposing numbers are eliminated.

Electronic recognition of a specific bus can also serve as the authorizing agent for dispensing fuel and fluids, preventing unauthorized use and theft.

#### *RF Transfer of Other On-Board Data*

In addition to transferring mileage and bus identification data from an electronic hubodometer, data from other on-board devices can be broadcasted to service line receivers. As described earlier, the engine ECM electronically controls several functions such as idle adjustment, fuel injection and timing. The engine ECM also contains vital operating information such as excessive idle periods, miles traveled, fuel economy calculations, and fault codes.

Since buses are fueled and inspected daily at the service line, an opportunity exists to make adjustments and extract data using RF technology. Operation of the system would require the bus to stop opposite a remote RF antenna. An on-board RF transmitting device, wired to the engine ECM, then broadcasts data to the service-line-mounted antenna. Since the flow of data is two-way, engine adjustments can be made by remote control.

If integrated with the J1708/VAN and J1939/Drivetrain data networks, the operating condition of any device on the network can be transmitted via RF signals to a central computer for storage and analysis. Figure 7-3 shows a conceptual drawing of how this system would function.

### Benefits to Bus Operations

The operations department can also make use of data generated from drivetrain integration. Of particular interest is data pertaining to idle time and operator actions such as hard braking and acceleration profiles. Agencies can use the data to identify operators with poor driving habits and retrain them to improve passenger comfort and increase bus life. Additionally, mileage data calculated by drivetrain can be applied to verify route distances and assist with scheduling.

## INFORMATION LEVEL INTEGRATION

### Background

The integration of Information Level components represents a new frontier for bus transit. Components typically integrated in this level include AVL with its

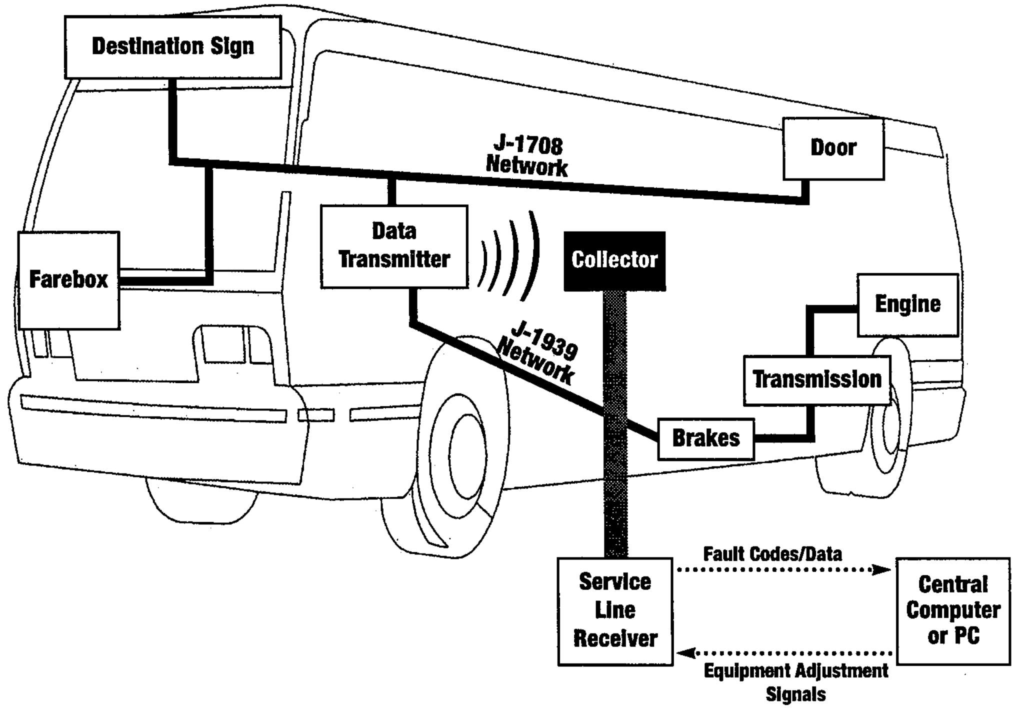


*Figure 7-3* *Radio Frequency technology can be used to transfer on-board data and reset or adjust components during service line inspections.*

global positioning system, the VLU, advanced radio communication with data capabilities, APC, next-stop annunciators, in-vehicle electronic displays, and electronic fareboxes.

Although this study has organized on-board electronics into three bus levels to simplify explanations, components can be integrated between bus levels to enhance benefits. For example, data from the drivetrain level can be integrated with the AVL and radio systems to provide an agency with real-time warning of mechanical faults.

Integration at the Information Level is custom for each application, based on the needs and abilities of each agency and integrator. Although the J1708/VAN data network and TCIP interfaces are in the process of being finalized, there are no universally accepted standards in transit to guide the integration. Nor is there consensus among agencies on how the technology will be applied, or how data generated from the integration will be used at the local or national level.

Some agencies have integrated a certain number of Information Level components on some buses, others have implemented them on a fleet-wide basis. Some agencies use an AVL system as the platform for the integration, others use a next-stop annunciator with its own integration and GPS location capabilities.

This section does not itemize the different approaches taken by agencies to accomplish the integration. Some of their experiences will be addressed in the next chapter. Instead, this section provides a broad look at the potential benefits made possible by the integration, with the understanding that not all benefits have been fully demonstrated.

### Basic Equipment

A brief overview of the key elements needed for Information Level integration will make it easier to understand how benefits are made possible. Although each application is different, the two foundation elements for on-board integration consist of:

(1) Advanced radio communication system with voice and data transmission capabilities, and

(2) AVL using a global positioning system (GPS) supplemented with other guidance technologies.

Other essential on-board elements include:

- GPS and radio antennas mounted on the bus roof;
- VLU;
- Operator's handset for verbal communication; and
- The operator's display terminal used to display and send text messages. It can also serve as a universal key pad to control other Information Level components.

Figure 7-4 shows the foundation elements of a typical Information Level integration.

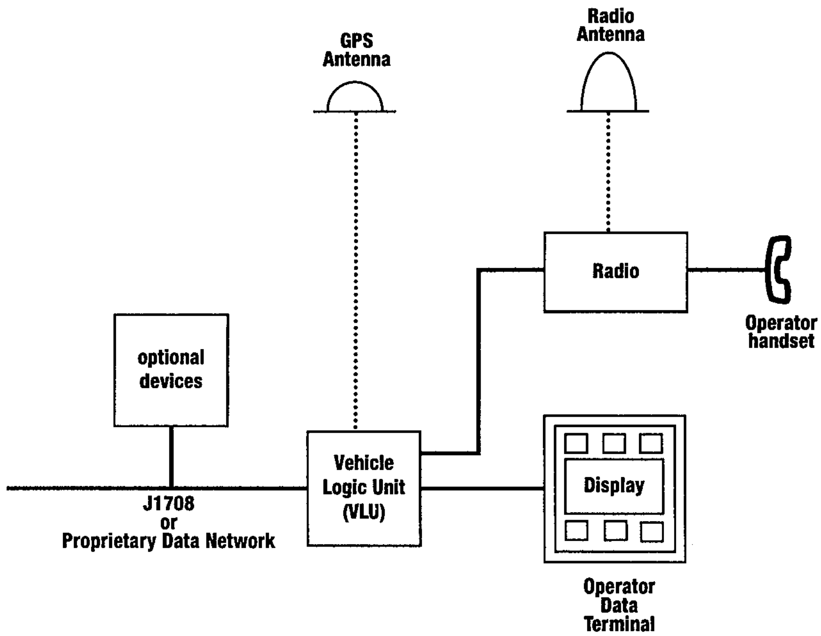


*Figure 7-4 Basic on-board elements required for a typical Information Level integration.*

The AVL and radio system provides the dispatcher and bus operator with essential vehicle monitoring and communication information. Vehicle location and schedule adherence information, established by the "smart" bus through on-board equipment, is transmitted to the transit agency via two-way radio communications. (Additional information concerning AVL and radio system operation was provided in the "Telecommunication Systems" section of Chapter 2).

*Operator's Display Terminal*

An important element to on-board Information Level integration is the operator's display terminal, which serves as the communication link between the bus operator and dispatcher. Mounted close to the operator for easy access, the on-board display is about 5 inches by 10 inches in size and performs multiple functions. It provides real-time updates of schedule adherence to the operator at various time intervals (i.e., one minute early, five minutes late, etc.). In addition to route adherence information, the on-board device can display a variety of text messages, allowing the dispatcher and bus operator to communicate without verbal conversation. Figure 7-5 shows the on-board display terminal mounted near the steering wheel for easy viewing.

Depending on the system, the dispatcher can send a variety of "canned" (i.e., pre-configured) text messages or create new ones as required. In return, operators can transmit several canned text messages to the dispatcher by depressing a category key and scrolling through a number of choices. For example, if a passenger becomes sick, the operator can select the appropriate message to inform the dispatcher and request a bus change. The dispatcher can respond with another text message indicating the time and location of the bus change.

In some systems, the operator can use the display terminal to send canned audio messages to passengers (e.g., no smoking allowed). The on-board display terminal can also be configured to serve as a single operator log-on for several electronic devices such as destination signs and fareboxes.

Push-button keys located on the terminal are either permanently marked with their respective func-

*Figure 7-5 Operator's display terminal serves as the communications link to dispatch.*

tion, or left blank with functions displayed on the display screen adjacent to the key. The later arrangement allows the key's function to change, providing greater flexibility.

Typical key functions include accident messages, equipment defect messages, disturbance messages (e.g., sick passenger, graffiti, etc.), and relief operator messages. If text messages are not sufficient, or an emergency exists, the operator can use the radio handset for direct communication. To establish verbal communication, the operator depresses one of two keys: request to talk (RTT), or priority request to talk (PRTT) depending on the urgency. Keys on the terminal also enable the operator to communicate with passengers over the PA system.

*Vehicle Logic Unit*

As described earlier, the heart of the AVL system is a VLU. The on-board microprocessor serves as the control center for the global positioning equipment, radio interface, operator's data terminal, and other on-board devices. The VLU is an essential component of the on-board system because it essentially makes the bus "smart" — knowing its geographic location, bus number and operator ID number at a minimum. As a collection point for on-board data, the VLU can also serve as an integration platform for other equipment such as next-stop annunciators and transaction-based fare collection.

### Transferring Data Files

Each electronically controlled component such as the farebox and the destination sign has its own way of transferring data to update files or software, or download information stored in memory. Fareboxes typically use infrared probes, while destination signs use programmable EPROM chips or floppy disks.

As central data storage devices, microprocessors such as the VLU and event recorders have the ability to store much larger data files. Data can include route and schedule information required by the AVL and next-stop annunciators, or transactional data produced from AVL, farebox, APC, and destination sign integration. There are several ways to transfer larger data files between the transit agency and bus.

One method involves the use of floppy disks or Personal Computer Memory Card Industry Association (PCMCIA) cards. Similar to a floppy disk, the PCMCIA card holds several megabytes of data. Inserted into the VLU or operator's display terminal, both can be used to update or download bus data files as needed by the agency. When used on a daily basis by the operator, the disk or card becomes the bus "key," containing information about the operators, their runs, and the bus itself. Regular use of a disk or card by the operator can be used to automatically update and download bus files and software on a daily basis. This procedure eliminates the need of having someone go from bus to bus inserting a card or disk.

The radio, in addition to transmitting voice/data messages and vehicle location in real time, can also be used to update bus files. The data transfer typically takes place during periods of radio inactivity when channels are free. Likewise, data stored on the bus that is not time sensitive (i.e., farebox and passenger count data) can also be transferred to the agency via the radio as channels become idle. The ability to use the radio to transfer data files depends on the unused capacity of the radio system, which at some agencies may be limited or non existent.

To overcome the problems associated with radio frequency overcrowding, data can be transferred via infrared or high-capacity radio-frequency link. The transfer can take place while the bus is being fueled on the service line, or when the farebox is being vaulted.

### Additional Equipment

In addition to radio and AVL systems, other devices such as destination signs, internal information signs, next-stop annunciators, wheelchair lift activity, and fareboxes can also be integrated. The extent to which the equipment becomes integrated depends on each agency's needs and the system integrator's capabilities. Integration of peripheral equipment can be accomplished with proprietary interfaces, an open data network such as SAE J1708/VAN, or a combination of the two. Potential benefits made possible by Information Level integration are categorized by bus operations, maintenance, and service line functions.

## BENEFITS TO BUS OPERATIONS

Of all departments, bus operations stands to gain the majority of benefits offered by Information Level integration. Integration of these technologies, which falls under the APTS division of ITS, has the potential to move buses and passengers more efficiently. When integrated with ITS, the benefits extend beyond transit.

As noted above, the intent of this chapter is to provide a broad range of potential benefits using best case scenarios. Benefits listed here assume that the integration has been fully optimized. However, to borrow a

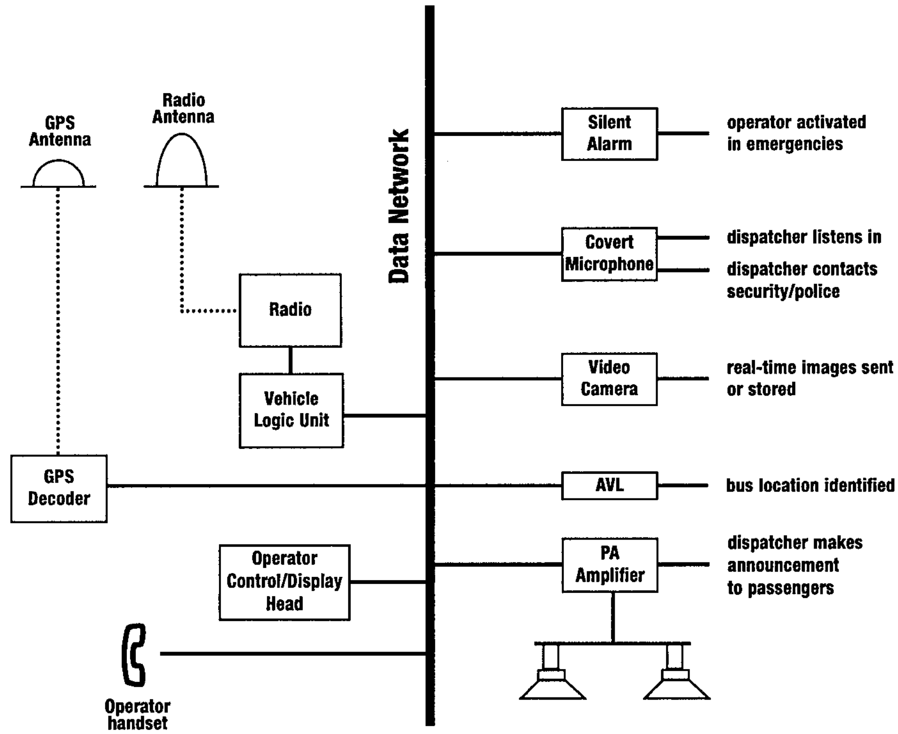


*Figure 7-6 Components integrated to improve on-board security.*

caveat used by automakers when disclosing fuel economy expectations, "... actual results may vary."

Potential benefits to bus operations are organized under three categories:

(1) Fleet Management

(2) Fare Collection

(3) ITS Participation

### Fleet Management

Benefits to fleet management encompass a broad range of Information Level technologies, each with the potential to improve the efficiency of bus operations. Technologies include AVL for locating and monitoring bus activity, advanced communication systems to transmit data to and from the bus fleet, and peripheral equipment such as APC and video surveillance cameras. Critical off-board equipment includes the radio communications infrastructure, dispatch consoles, and database management tools such as CAD software systems for planning routes and scheduling.

The primary fleet management benefits include the potential for:

- Increasing security for the operator and passengers;
- Improving fleet utilization, resulting in fewer buses and non-revenue miles traveled;
- Improving service, resulting in increased ridership; and
- Improving response time to service disruptions.

Specific examples are summarized below.

*Increase Passenger and Operator Security*

Integrating AVL with advanced on-board communication systems has the potential to enhance operator and passenger security in several ways. Silent alarms, triggered by the operator, combined with bus location information can decrease the response time of security personnel. Activated by the operator in time of crisis, the silent alarm allows the dispatcher to instantaneously determine bus location. Covert microphones, that become active only when the silent alarm is tripped, let the dispatcher listen in on conversations and determine the severity of the incident and respond accordingly.

If on-board surveillance cameras are integrated with the radio system, real-time images can be sent (with adequate radio capacity) to the control center to obtain a better indication of the incident. If not sent in real-time, images can be stored to identify the perpetrator(s) when the bus returns from service. On-board cameras can also be used to identify vandals, or assist agencies to determine the cause of slip-and-fall accidents. Figure 7-6 shows the integration of specific components needed to improve on-board security.

*Improved Operating Efficiency and Passenger Service*

Information Level integration has the potential to

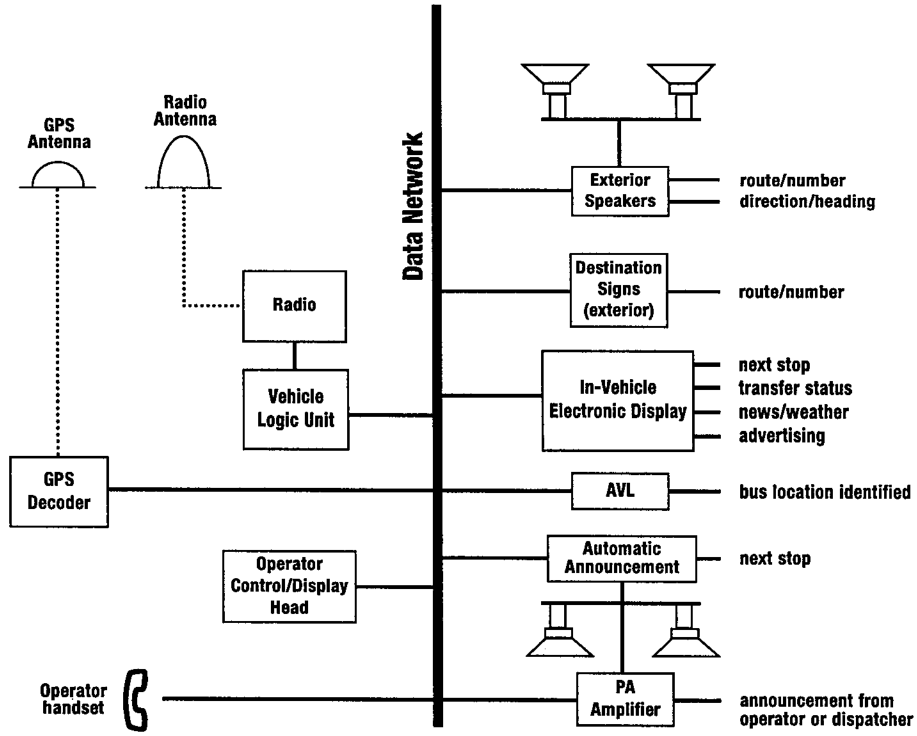


*Figure 7-7* *Components integrated to provide in-vehicle passenger information.*

improve operating efficiency and passenger service in several ways:

- Communication with bus operators via text messages reduces the amount of "chatter" over the radio and ensures accurate transmission of information.
- Text messages can be sent to any number of buses to inform the operator of construction sites and detours, threatening weather, and other conditions.
- Monitoring and controlling bus movements enables agencies to reduce platooning, layover time, and non-revenue deadhead time.
- Monitoring times between bus stops permits agencies to fine-tune their schedules to reflect actual bus arrival times and to coordinate transfer connections.
- Improved on-time performance helps promote passenger satisfaction and ridership.
- Bus location information discourages operators from making unauthorized trips/stops during layovers or deadhead travel times.
- Integrating AVL with automatic passenger counters (APC) and the wheelchair lift allows agencies to determine the optimum number, size, and type of buses needed for specific routes.

*Increased In-Vehicle Passenger Information*

Several electronic technologies can be integrated to provide passengers with helpful information. Equipment includes electronic information displays, public address systems, and automatic next-stop annunciators. In addition to enhancing passenger service and convenience, the equipment can be used to satisfy ADA requirements by providing audio and visual announcements of major stops and transfer points.

Next-stop annunciators, either integrated with AVL or installed as a stand-alone system, provide automatic and pre-recorded voice announcements of bus stops. To supplement audio announcements, interior signage provides visual information for the hearing impaired. Audio and visual equipment can also be used for public service messages, news, weather and advertising.

Public address systems integrated with the radio allow the dispatcher to make announcements within a particular bus, to several buses, or the entire fleet. Figure 7-7 shows the integration of components required to provide in-vehicle passenger information.

## Fare Collection

Integrating the farebox with other electronic devices enables it to accept non-cash revenue such as magnetic tickets, stored value smart cards, and bank-issued credit cards. Non-cash fare media have the potential to provide several benefits:

- Reduce lost revenue due to fare evasion;
- Reduce costs associated with counting and handling dollar bills, coins, tokens, and transfers;
- Increase customer convenience by enabling passengers to travel between agencies using a single form of payment;
- Encourage a more flexible fare structure by taking into account factors such as distance traveled and off-peak times;
- Enable financial arrangements to be made with certain groups such as employers willing to subsidize employee fares; and
- Increase transit revenue by taking advantage of the interest earned on the unused portion of prepaid fares.

*Integration Enhances Data*

In addition to accepting non-cash payment, the farebox can be integrated with other on-board bus devices to enhance revenue and passenger data. Linking the farebox with AVL, APC, VLU, destination signs, and other equipment has the potential to overcome many of the problems inherent with farebox data.

Many of these problems are due to operators failing to enter one of three functions: the proper identifier at the beginning of the run, the correct fare type, and entering a new code when changing routes (21). As a result, much of the data generated by the farebox is not fully utilized. Farebox integration can improve the chances of obtaining clean farebox data, and to enhance the value of that data by correlating them with other sources.

One obstacle to farebox integration lies with the cautious approach taken by some farebox manufacturers with regard to data transfer (21). Concerns include sharing data with other components, which may compromise the proprietary nature of the farebox's operating system and the security of revenue data. Despite the issues at hand, farebox integration can provide several potential benefits.

*Transaction Database Possible*

The most significant benefit offered by farebox integration is that it allows an agency to analyze fare data through a transactional database. Unlike a typical summary approach where data is stored in a cumulative manner, a transactional database establishes a record for each transaction. Segmenting data by transaction offers greater analysis flexibility. Agencies can track fares by stop or route segment. They can also track fares issued by other agencies to establish linked travel patterns.

Farebox integration can take place with several on-board systems and components. Integration with destination signs, for example, can improve the operator's chances of entering the correct route since incorrect destinations are easily recognized by passengers and generally reported to the operator. One method involves configuring the farebox keypad to control the destination sign and other devices that require operator input. In addition to improving the accuracy of farebox data, use of a single keypad for multiple functions simplifies the operator's job.

Integrating the farebox with AVL places a time and location stamp for each passenger boarding, permitting agencies to determine the number and type of passenger boardings at specific stops. If the agency does not have an AVL system, integration with an odometer (supplied by the speedometer or drivetrain component) can provide similar location information. Another alternative involves the use of an automatic next-stop annunciator system with a global positioning system and/or other technologies to determine vehicle location.

Integration with door controls is also important because it can be used to signal each transactional record. Every time the front door opens, a new fare record is created. When the door closes, the record ends.

All devices integrated to enhance fare data can be tied to the VLU, which stores each transactional record. The VLU also provides a convenient means of downloading the data. Figure 7-8 illustrates the various components and systems needed to enhance fare data.

### ITS Integration

Integrating Information Level technologies with other ITS activities enables transit to become an essential part of a seamless national transportation system. Instead of operating as an independent entity, transit can become linked with other surface transportation modes. When the NTCIP/TCIP interface projects are operational, information between transit buses and the rest of the ITS community will flow in both directions. Until then, gateways can provide similar benefits with certain limitations.

As examples of ITS integration, transit can provide information on routes, fares, parking availability, traf-

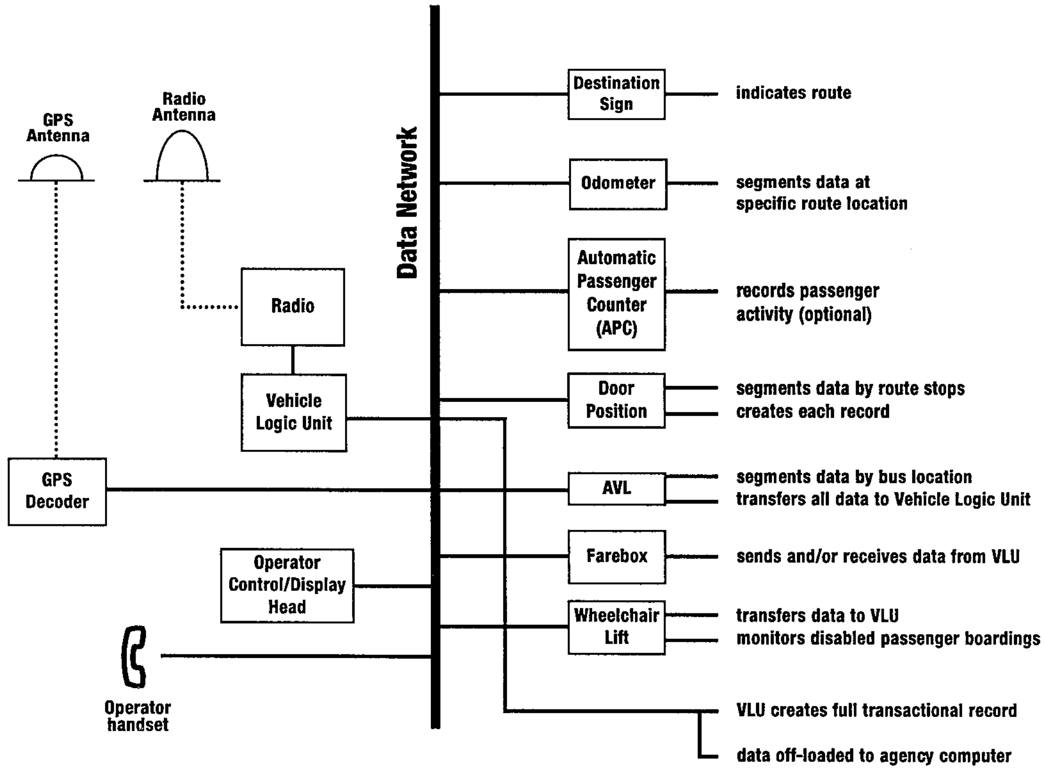


*Figure 7-8* *Components integrated to improve the accuracy of fare data.*

fic flow, and the status of bus service in real time. In return, transit can receive information on traffic congestion, road construction, and special events to plan service accordingly. Additionally, traffic signal priority can help improve transit's on-time performance, along with public's acceptance of bus travel.

Information can be provided to travelers prior to making the trip or while en route. Pre-trip information can be accessed through a variety of media including telephones, personal computers, and cable televisions. While en route, travelers can access information at terminals or kiosks using a variety of audio and visual displays.

Providing travelers with accurate information allows them to choose among a variety of transportation modes. The efficient movement of vehicles on roadways resulting from improved trip planning also has the potential to reduce traffic congestion and air pollution.

Compliance with NTCIP/TCIP interfaces will also allow agency departments to exchange data among themselves using a standard format. Exchanging data with other agencies has the potential to facilitate fare integration and permit agencies to compare several performance indicators such as schedule adherence, road calls and specific equipment performance.

## BENEFITS TO MAINTENANCE & SERVICE LINE FUNCTIONS

Critical driveline data, provided by individual components and collected by a data recorder or VLU, can be sent to the radio and transmitted in real time to the agency (See Figure 6-3). Included are alarms for low oil pressure, high coolant temperature, and indications of when the operator repeatedly overrides the engine shut-down system. The agency can also monitor any performance indicator of its choosing as a method of detecting impending failures.

Benefits to service line functions have already been addressed in the section on drivetrain integration. Virtually any component controlled electronically can be integrated to the VLU or similar on-board data collection system. Fault codes and performance characteristics that exceed established parameters can be transferred via radio frequency signals to a service line receiver. Making component performance data available on an exception basis when the bus is in for daily servicing has the potential to detect abnormalities in advance before they become major problems. RF signaling can also be used to make equipment adjustments while other service line functions are being attended to (See Figure 7-3).

# TRANSIT SYSTEM EXPERIENCES: REWARDS AND RISKS

This chapter highlights some of the experiences associated with advanced electronics. Also included are expansions planned by two large agencies.

In addition to the many beneficial experiences, some of the risks associated with the technology are also included. Doing so is not intended to undermine the technology or the industry's ability to effectively put it to use. Instead, a balanced examination will give agencies a better indication of what they may encounter when integrating the technology.

The material presented here does not claim to represent all experiences — a great deal of material has already been published on the subject. Nor does this chapter attempt to compare the strengths and weaknesses of specific agencies and suppliers. In fact, supplier names have been omitted to avoid direct product comparisons. So have the names of agencies reporting difficult experiences.

Transit agencies are encouraged to contact those with experience in advanced electronics to learn more about their success and failures, and what they did to resolve problems.

## SUMMARY

There are many examples where electronic integration has contributed to the betterment of bus operations and maintenance. There have also been significant drawbacks. With regard to multiplexing and drivetrain integration, experiences have been essentially positive, primarily because the technologies were first proven in other industries and integrated into the bus by the bus builder.

Relatively new to transit, Information Level integration has produced mixed results. Many of the positive experiences, presented here and elsewhere, include:

- The ability to track buses in real-time and modify service to meet customer needs;
- Improved on-time performance and the ability to make timely transfer connections;
- Improved communication between bus operators and dispatchers;
- Improved in-vehicle communication with passengers;
- The ability to track passenger activity per fare transaction to accurately plan routes and bus utilization;
- The ability to monitor on-board mechanical indicators in real time; and
- Improved paratransit service due to computerized dispatching assistance.

Although the benefits are well known and actively promoted, many of the disadvantages associated with the integration have not been openly documented. They include:

- Integrating equipment around proprietary systems that limit expansion and interoperability with other components and systems;
- Increased maintenance costs;
- Shoddy workmanship by some subcontractors hired to install equipment as retrofits;
- Dispatchers and operators who revert back to old practices because the new technology does not function as planned;
- Bad press accounts that denounce "star wars" technology as wasteful transit spending;
- Staff reductions that coincide with the delivery of new technology that brings with it additional manpower requirements; and
- Inadequate documentation by vendors, making it difficult for agencies to properly train personnel and maintain/repair equipment.

Difficulties have resulted in delays, cost over-runs, and legal disputes. They have also caused some integrators to abandon the transit market and their customers.

This chapter also discusses the plans of VIA Metropolitan Transit in San Antonio, and New Jersey Transit (NJT) to expand existing electronic applications. As one of the oldest AVL installations, VIA has applied the lessons learned from past experiences. NJT is supplementing its existing signpost-based AVL system with a highly advanced automatic passenger counter system that will help the agency better plan its service.

## DRIVETRAIN INTEGRATION

### Beneficial Experiences

Drivetrain Level Integration serves as a model for sharing data between electronically controlled components. Without question, drivetrain integration has been fully accepted by bus transit as a valuable asset. All components are compatible with data networks developed by the SAE, and supported by component and vehicle manufacturers and end users. Standards defining the seamless transfer of data between components were established in advance, allowing manufacturers to offer fully integrated products from the start. Component interchangeability made possible by the use of standard data networks also gives bus builders and transit agencies greater product flexibility.

Standardized diagnostic ports allow technicians to use a variety of tools to extract fault codes and other performance data. Interface with AVL and radio systems allows drivetrain data to be transmitted in real-time back to the agency. Data can also be downloaded on the service line using a short-range wireless RF link.

*Chicago Makes Use of Expanded Data*

The large amount of data generated from drivetrain components can be useful to agencies. The Chicago Transit Authority (CTA) has purchased a software package that gives them additional data pertaining to vehicle performance and driveability. CTA examines a number of operating conditions for a given bus over a specified period of time. A summary report indicates:

- The total number of gallons of fuel consumed per bus, broken down by idle time, driving time and miles per gallon;
- Hard braking applications by the operator;
- The number of mechanical warning signals given to the operator; and
- The amount of time a particular engine spent idling, operating, or shut off.

Several additional reports can be generated depending on the agency's needs. As an example, Figure 8-1 plots the maximum coolant temperature for a specific CTA bus over a 900 hour period.

Expanded engine data has allowed CTA to take specific action. Since new bus specifications have an average fuel economy requirement tied to financial penalties, CTA uses the engine data to verify manufacturer's claims. Actual in-service fuel economy data is also shared with the manufacturers to help them optimize operating efficiency for CTA's fleet. Data pertaining to brake applications, transmission gear range, retarder applications, and fuel economy also allows CTA to optimize drivetrain components to improve brake lining life.

Engine data has made CTA aware of just how much time buses spend idling. As a result, the agency now programs engines to shut themselves down automatically after 30 minutes of idle time.

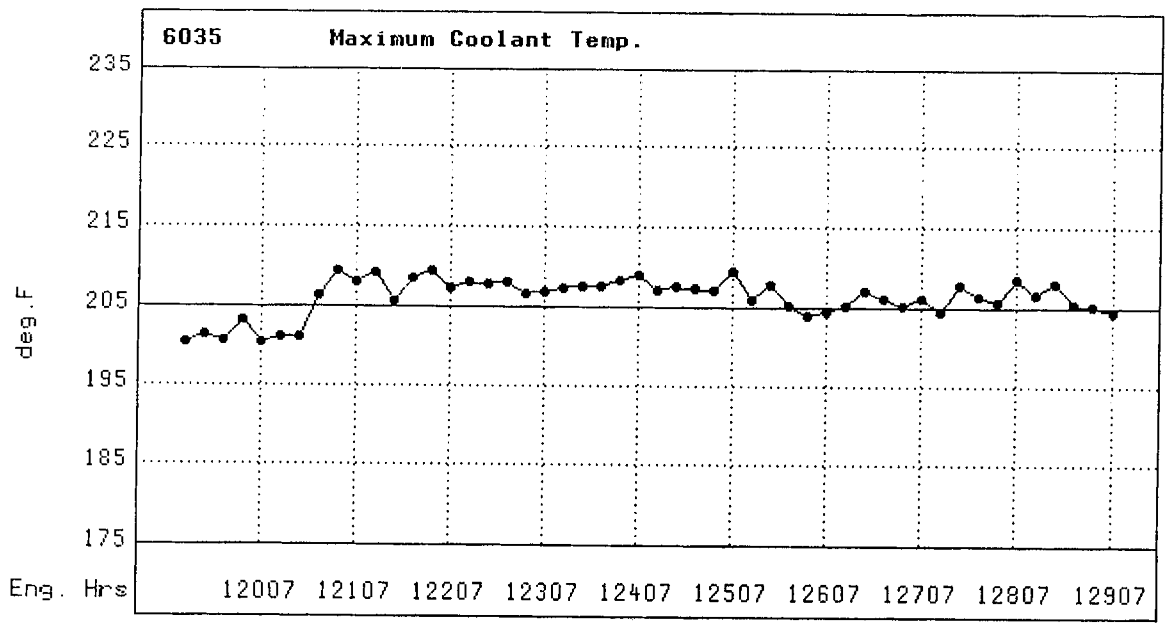


*Figure 8-1* ***Report showing maximum coolant temperature achieved over a 900-hour period.*** *(Courtesy of Chicago Transit Authority)*

*Ann Arbor Monitors Mechanical Indicators in Real-Time*

Ann Arbor Transit Authority (AATA) has integrated its AVL/radio system with the drivetrain to obtain performance indicators in real time. Information produced by the monitoring caused AATA to reverse a policy on vehicle allocation.

In an attempt to reduce costs, the agency decided to use a smaller bus on a particular route. However, when on-board monitoring revealed that the extra passenger loading increased coolant and oil temperatures, the agency reverted back to the larger buses. The same data could have been obtained through a physical cable connection. Monitoring the data in real time, however, made the problems more obvious.

The agency also recognized a low-oil-pressure condition on one of its revenue service buses, which saved them the cost of an expensive overhaul.

*Long Island Integrates Engine, Wireless RF, and VAN*

MTA Long Island Bus uses wireless RF technology to control certain bus functions as it enters and exits the agency's facility. All 173 of its Compressed Natural Gas (CNG) buses are equipped with a methane detection system tied to a J1708-based VAN. As CNG buses return from service through the terminal gate, a RF signal shuts down all but one of the CNG tanks. As buses exit the facility, the wireless system automatically reactivates the tanks. Isolating CNG tanks within the facility reduces the risk of gas leakage and fire.

The on-board methane detection system is also integrated with other bus and facility functions to improve safety. If gases within the bus reach 20 percent of the lower explosion limit (LEL), an audible alarm is sounded inside the bus, a strobe light activated on the bus roof, and an alarm signal is sent to the dispatcher and foreman. At 50 percent of the LEL, an additional set of safety features are automatically put into action. If the bus is running, the system shuts down the engine. If located inside the storage facility, the system activates the building's exhaust fans and opens its doors to maximize ventilation.

Engine control modules (ECMs) are also integrated with the on-board VAN and the wireless RF system. As buses return from service the bus I.D. number, accumulated mileage, and any mechanical alarms stored in the ECM are downloaded over the wireless link. CNG buses are also equipped with next-stop voice annunciators.

During its next phase, MTA Long Island Bus will equip the entire fleet with AVL and integrate it with next-stop annunciators, fareboxes, and destination signs through the J1708-based VAN. Integration will allow the operator to use the display terminal to initialize the next-stop annunciator, farebox and destination sign functions.

Except for initial "teething" problems and an occasional false alarm generated from methane detection and engine alarms, MTA Long Island Bus reports that the system is working well. They continue to troubleshoot the system, reducing the number of false alarms and other failures.

## Other Drivetrain Integration Issues

There are a few issues associated with drivetrain integration that agencies should be aware of. The most significant is that agencies are not fully utilizing available data from the equipment.

Virtually every agency obtains basic fault-code data from drivetrain components to assist with diagnostics. However, few make use of the vast amount of additional data available from these components, especially the engine ECM. One reason cited involves the extra costs associated with the software packages. A stronger point, however, is that most agencies simply do not have the resources needed to analyze all of the data generated from the software programs.

While some transit agencies are beginning to use AVL/radio, on-board data recorders, and RF links to store and transmit drivetrain data, overall applications are limited. One major supplier of automated service line equipment developed a wireless approach for automatically downloading vital on-board bus conditions at the service line. Due to lack of interest, however, the project was discontinued.

*Real-Time Data Concerns*

With regard to monitoring drivetrain functions in real time, agencies have expressed mixed feelings about it. While some value the ability to monitor drivetrain functions in real time, others question the need since components already have built-in data storage and protection features. They argue that drivetrain components can be configured to protect themselves during a failure, and in the case of the engine, completely shut itself down if necessary. In addition, severe fault codes are sent to the operator, while others can be detected during regular service intervals.

The bottom-line concern expressed by those who oppose real-time monitoring is that they do not have the resources to deal with the data. Few in maintenance question the benefit of using timely data to predict and prevent equipment failures. However, they simply lack the manpower.

At one agency, false alarms from the monitoring of mechanical indicators in real time produced an average of four additional road calls per week. As a result, the real-time monitoring of mechanical indicators was discontinued.

*SAE J1939 Compatibility*

Another issue concerning drivetrain integration involves compatibility with the new SAE J1939 data network. Newer buses are being delivered with the next-generation, J1939-compatible drivetrain components. Agencies typically separate engines and transmissions during the rebuilding process, later combining units that were not "married" originally. Replacing a J1939-compatible component with a non-compatible one can cause interface problems.

## ELECTRICAL SYSTEM MULTIPLEXING

### Beneficial Experiences

Transit agencies have accepted multiplexing as a welcomed replacement for traditional "hardwired" electrical systems. With adequate training, technicians have acclimated themselves to the general principals of operation and troubleshooting. Additionally, agencies report trouble-free operation, giving them time to become familiar with the system. A popular feature is the diagnostic LED lamps that allow technicians to visually determine if control signals have reached a certain location.

Manufacturers have also embraced multiplexing because it allows them to satisfy the requirements of each bus order without adding much engineering time or electrical hardware. Likewise, agencies can make electrical system changes easily and quickly with appropriate equipment and training.

### Other Issues

Despite the many benefits identified here and in Chapter 4, there are other aspects to multiplexing that must be considered.

*Training*

As with any new bus system, multiplexing requires additional maintenance training. The training is needed to describe the general theory of operation and use of self-diagnostic and troubleshooting procedures. If agencies want the capability to make program changes, a laptop computer with appropriate software is required, along with a higher level of system understanding. Without this capability, agencies must pay the bus manufacturer to make program changes on site.

*Proprietary Operating System*

Since existing multiplexing systems are based on proprietary data networks, replacement parts for the operating system itself are unique and limited to authorized distributors of the product. Although failures are limited, agencies report that most components are not field repairable. Some agencies claim that the cost to have modules and other components repaired or replaced on an exchange basis is expensive. Others report that they lacked funding to purchase optional equipment needed to facilitate diagnostics.

*Two Different Systems*

Agencies that receive different multiplexing systems on separate bus orders must maintain two sets of spare part inventories. They must also arrange for training and programming on both systems. Although any new bus order requires additional spare-parts inventory and training, two different multiplexing systems only adds to the requirements. In addition, older buses cannot be easily retrofitted with multiplexing unless a complete overhaul is performed.

*Relays & Power Wires Still Required*

Contrary to popular opinion, all electro-mechanical relays are not eliminated with multiplexing. Depending on the rating of each multiplex system, separate relays are still required to handle high-amp-draw devices such as engine starters. Some multiplexing systems have the ability to handle higher amp loads and therefore require fewer relays. Regardless of the number, additional relays require another set of power and ground wires to operate.

As a power-switching device, the I/O modules of some multiplexing systems actually incorporate electro-mechanical relays into their design. Other designs use solid-state electronic relays. While the large number of relays traditionally grouped together in the central electrical panel are reduced, relays have been "repackaged" into modules located closer to the devices they control.

Furthermore, each I/O module located throughout the bus must be supplied with "hard wired" power and ground wires (see Figure 4-5). Wires are also needed to connect existing electrical switches and devices to each I/O module. Although the wiring is less than in traditional systems, multiplexing still requires a fair amount of electrical wiring. In addition, damage to the data cable, I/O module or microprocessor can render a good part of the electrical system inoperative.

*Insufficient Capacity, Special Tools*

Some agencies report that they failed to specify an adequate number of spare on-board I/O modules to accommodate electrical system expansion and modifications. Adding new modules to the system was expensive. In addition, traditional "test lamps" are not recommended for troubleshooting some systems because they draw too much current. High-impedance volt meters are recommended instead.

## INFORMATION LEVEL INTEGRATION

### General Observations

Before highlighting agency experiences with Information Level integration, there are several general observations that can be made. One of the most striking is the distinct difference between the experiences reported formally and those described in frank discussions with agency personnel. Much of what has been formally presented tends to downplay the risks associated with the technology and presents experiences in an idealistic manner.

Ignoring the technology's risks is analogous to the "halo effect," a term used by automotive analysts to describe car buyers who steadfastly defend their purchases despite any negative experiences. Concealing these experiences does not give future buyers a true indication of what to expect, which could produce negative results. For example, agencies that only hear success stories could end up with equipment that they are not prepared to operate or maintain adequately. As a result, equipment may not deliver the intended results through no fault of its own.

In reality, on-board Information Level integration is an extremely complex subject that requires a great deal of time, effort, understanding, and funding to implement effectively. Agencies who become aware of a wide variety of experiences in advance will be in a better position to implement technology that addresses their needs in a cost-effective manner.

## POTENTIAL REWARDS

### Overview

Publications are available that highlight the benefits of ITS and APTS technologies. Most of the material is positive and tends to emphasize the benefits without taking into account the underlying efforts and expenses needed to implement the technology. One example is a study that estimated the benefits resulting from APTS technologies but did not include any of the costs (vehicle or wayside) associated with implementing those technologies. All financial benefits were based on the assumption that the equipment was already in place and paid for.

This section will not attempt to verify existing benefit assessments or to undertake a cost/benefit analysis of individual agencies or the industry at large — that is beyond the project's scope. Several programs are underway that will provide a more accurate reflection of the costs and benefits associated with APTS technologies:

(1) University of California, Berkeley, study concerning paratransit in Santa Clara County.

(2) North Carolina State University study on Winston-Salem concerning CAD benefits.

(3) University of Michigan study on Ann Arbor evaluation.

(4) Volpe Center evaluation of Denver and Atlanta APTS technology implementations.

Cost/Benefit analyses were difficult to obtain. Some agencies admitted that they never prepared one. Others were uncomfortable sharing studies that were done. Systems integrators who stand to gain from such analyses, could not come up with one either. In reality, there are several factors that make a cost/benefit analysis difficult to undertake:

- Much of the technology has not yet been fully implemented at agencies;
- Each agency has its own unique set of functions and needs, making the integration "custom" for each application;
- Prices vary from agency to agency (i.e., larger agencies are typically given discounts for large-volume purchases, some vendors may lower prices to gain a foothold in transit, etc.);
- Many benefits are difficult to measure, such as the relationship between on-time performance and increased ridership, or faster emergency response time and passenger/operator security;
- Cost/benefit studies become obsolete quickly because of fast-paced technology enhancements and pricing fluctuations; and
- Lack of standards allows a wide range of equipment, each with different interfaces and capabilities, making it difficult to make an "apples-to-apples" comparison.

## Ann Arbor Pioneers Wide-Scale Integration

Ann Arbor Transportation Authority (AATA) is one of the most comprehensive examples of advanced on-board electronic integration. Known as The Advanced Operating System (AOS), the GPS-based AVL and advanced radio communication system is operational on a fleet of 92 fixed-route, paratransit and supervisory vehicles. The 800 MHz radio system features one channel for voice and one for data transmission. Other features of the AOS include:

- AVL with differential GPS;
- Computer aided dispatch (CAD), computer aided transfer management, and headway analysis management;
- Next-stop annunciators and interior signage;
- Automatic passenger counters (APC);
- Engine interface for real-time data transmission;
- Video surveillance; and
- Generation of reports including those for FTA's National Transit Database (i.e., Section 15) reporting.

Updating on-board data files is currently accomplished with PCMCIA disks. The agency is evaluating radio use or an RF link. To keep the entire network current and running smoothly, the agency has hired one additional staff person. Existing staff members have been given additional responsibilities based on the technology's capabilities. On-board integration is accomplished by a combination of proprietary and SAE J1708 data networks.

### *Vehicle Location*

Each bus is equipped with a GPS receiver, providing the agency with location information. Differential corrections allow the bus to calculate its position within seven feet (two meters). Using location data transmitted from the bus, the system tracks the progress of each bus and alerts the operator if he/she is off schedule. Displays at the agency track the progress of each bus, including the distance between them on the same route and adherence to established schedules. Information generated by the displays is used to dispatch extra buses or to re-route existing ones.

AVL data are incorporated with other data collected by the system, including fare collection information, passenger counts, and engine operating conditions to provide a more comprehensive data base. The agency is using the data to optimize routes, schedules and fleet utilization.

In addition to determining vehicle position, GPS also provides the correct, synchronized time to each vehicle.

### *Operator's Display Terminal*

An on-board display terminal serves as the operator's interface with the radio and VLU. The VLU contains route and schedule data, while the radio minimizes voice transmissions by using a data channel to send text messages to and from the dispatcher. Text messages are used to communicate schedule adherence, operating conditions, and other information provided by the dispatcher. Voice communication is also possible by switching the radio to a voice channel. AATA reports that data messages have improved the communication accuracy with operators, and reduced non-essential voice "chatter."

### *Transfer Management*

The transfer management system helps passengers make transfer connections. Using the display terminal, bus operators send transfer requests to the dispatcher's computer, which calculates whether the connection can be made. If a transfer is accepted, the dispatcher sends a text message to the appropriate bus advising the operator to wait at a specific intersection.

### *En-route Information*

An on-board passenger information system, integrated with the AVL, consists of a public address (PA) system, interior LED sign, and exterior destination sign. Using the display terminal, operators can play pre-programmed announcements over the PA system to inform passengers of special events. Announcements to passengers can also be made by the dispatcher, which not only provides essential information but helps create a safe and secure environment.

A two-line LED interior sign automatically informs passengers of the route, time, and next stop based on information provided by the AVL. Exterior destination signs are also updated automatically using AVL data when the bus changes direction or route.

### *Traveler Information*

Real time data generated from the AOS is used to display actual arrival and departure times on monitors located at the agency's downtown transit center. The infrastructure is also in place to integrate real-time operational data on the agency's Web site.

*Integrated Keypad*

Keypads once used for registering fare transactions on the fareboxes have been incorporated into the operator's display terminal, which automatically stamps the time and location for each fare transaction. Data is stored in the agency's central database, which is being analyzed for future route development and assessment.

*Drivetrain Indicators*

Data taken from the electronically controlled drivetrain are integrated with the on-board VLU computer and AVL to send alarms and other operating conditions to the agency in real time. Additionally, when an operator reports an emergency, corresponding drivetrain data are automatically recorded and stored in the on-board VLU computer.

*Covert Alarm/Microphones*

If the operator encounters passenger difficulty on the bus, he/she can activate a covert alarm to silently inform the dispatcher. The dispatcher can then listen in to monitor the situation. Operators also use the alarm system to inform the dispatcher of an accident to the bus, or situations that cause traffic delays or rerouting.

*Video Surveillance Cameras*

A portion of the bus fleet is equipped with a three-camera video surveillance system that records images on videotape, similar to a home VCR system. Other buses are equipped with a two-camera digital system that features computer-based playback. AATA reports that passengers are pleased with the added security afforded by the cameras, and that buses are cleaner because of them.

Although operators were initially reluctant about the "big brother" implications of on-board cameras, the agency reports that they now understand the benefits. Cameras, equipped with microphones, help managers to mediate fare disputes between operators and passengers. In one case, a student threatening another student with a gun was caught on video and the tape turned over to the police, who used it to identify the assailant and proceed with charges.

*Passenger Counters Planned*

Certain fixed-route buses will be equipped with an integrated automatic passenger counting (APC) system that tracks passengers boarding and exiting the bus. The data will be combined with other data and used to evaluate ridership patterns and develop future routes.

*Smart Cards Evaluated*

Ann Arbor's AOS project actually began as a vision to implement smart cards. The intent was to utilize more than 60,000 cards used by University of Michigan students, who make up a significant portion of the agency's ridership. After several tests, the agency found that insertion rate (more than four seconds per transaction) was too slow for passenger boardings. The agency has determined that proximity cards would be more suitable for transit, and is examining potential vendors.

*Paratransit Applications*

Included in the AOS system are 16 paratransit vehicles. Operators receive their entire schedules over the on-board display terminal, which also records the date, time, and location for each arrival and departure throughout the day. A special software program allows the agency to manage paratransit reservations, scheduling and integration with fixed-route bus service. The display terminal continually updates the operator in real time of new reservations and cancellations. Paratransit schedules are continuously being developed and revised based on data generated by the real-time reservation system.

*Major Benefits Summarized*

AATA firmly believes that the new technology embodied in its AOS is the only viable way to attract passengers from the single-occupant automobile. Major benefits include:

- Passengers have been positive about the technology, especially on-board announcements and displays;
- Using text messages to communicate with operators has greatly reduced misunderstandings;
- The ability of dispatchers to follow bus movements visually allows them to react more quickly to incidents; and
- Data produced from the system will allow the agency to track on-time performance, evaluate existing routes, and plan future routes based on precise data.

## Milwaukee Defines Objectives; Uses 3-Phase Acceptance Test

*Background*

Milwaukee County Transit System (MCTS) released a request for proposals (RFP) for a CAD/AVL system in 1991, awarded a contract in 1992, completed installation in 1994, and accepted the final system in late 1996. Essential components of the system include a GPS-based CAD/AVL system, new trunked radio communication system, and corresponding radio and location equipment installed on all 543 buses and 59 support vehicles.

MCTS is pleased with the overall procurement. Among other factors, the agency attributes success to clearly defining objectives and incorporating a detailed three-phase acceptance test into the specification.

### *Objectives Defined*

Before developing the system specifications, the agency defined three objectives:

(1) Replace the radio/dispatch system that had been in place since 1977;

(2) Improve schedule adherence and efficiency; and

(3) Improve operator/passenger security through a silent alarm feature.

The objectives became the guiding factors for decisions made during the system installation process. They also became the yardstick for measuring the project's success.

### *3-Phase Acceptance Test*

Since the successful bidder did not have extensive transit experience, and GPS technology had not been applied in transit, the project team decided to incorporate a three-phase acceptance test. Completion of each phase was integrated with the payment schedule. Failure at any point in the testing required the vendor to correct the problem before proceeding.

The Phase I test involved a examination of control center functions and a review of AVL's performance on 13 buses and two supervisory vehicles. Testing of control center hardware and software was accomplished through a simulation of normal service conditions. The review of on-board system operation involved driving out-of-service vehicles.

Phase II of the acceptance test demonstrated system performance with the entire fleet online. Demonstrations included dynamic radio channel allocation, route and schedule adherence, transmission of data messages, silent alarm operation, and report generation for both online and stored data.

The final phase involved 30 days of consecutive revenue service experience without a major component failure. If a major component failed, a new 30-day test began again after all repairs were made. Minor failures required stopping the clock, making the repairs, and restarting it once repairs were made. "Major" and "minor" failures were fully defined in the specification.

### *Benefits Obtained*

Since operating its new AVL/radio system, the number of off-schedule buses has been reduced by 40 percent. Off-schedule buses are defined as those operating outside the window of one minute early to three minutes late. The schedule department is reviewing running time reports to determine schedules and service levels more accurately for each route.

In addition to sending and receiving data and voice messages the radio system also prioritizes calls, thereby improving response time to urgent calls. In a security situation, the operator can depress a silent alarm, which changes the on-screen bus icon to red, allowing the dispatcher to immediately identify bus location. During a silent alarm the system also identifies the nearest supervisory vehicle on the screen automatically. A covert microphone on the bus is also activated, allowing the dispatcher to monitor the severity of the situation.

MCTS reports that its new AVL/radio system has also improved relations with law enforcement officers. During an incident police are sent to an exact location, not an estimated location, which has improved response time and eliminated frustrating searches to find buses.

## Winston-Salem Enhances Paratransit Service

### *Background*

The Winston-Salem Transit Authority (WSTA) is participating in a multi-phase Mobility Manager project to implement several ITS technologies. In 1995, WSTA completed Phase 1 of the project, which consisted of implementing a CAD system to all 20 vehicles used in its Trans-AID paratransit service. In three of the paratransit vehicles, data terminals, AVL and contactless smart card readers were also installed and integrated with the CAD system.

### *Phase 1 Results*

WSTA conducted an evaluation of the Phase 1 CAD implementation. Overall evaluation results include (73):

- CAD software allows dispatchers to schedule more passengers per day with the confidence that vehicles will not be over-booked.
- Prior to CAD, almost all paratransit trips required 24-hour advance notice. As a result of CAD, approximately 10% of the trips are same day.
- Passenger wait time has decreased over 50 percent.
- Based on a capital cost of $100,000, the approximate cost per passenger trip is 20 cents, which represents 3.5 percent of the total operating cost per trip.
- Passenger trips increased 17.5 percent, vehicle miles increased 25.1 percent, vehicle hours increased 32.0 percent, and the client base increased 100 percent as a result of a larger service area and increased same-day calls.

WSTA also determined that on-board data terminals require a dedicated radio channel and additional storage capacity to avoid transmission delays as larger groups of passengers use smart cards.

### San Antonio Applies Lessons Learned

*Background*

VIA Metropolitan Transit in San Antonio, Texas, began using its first-generation, signpost-based AVL system in 1987. When the existing AVL and radio communication system needed to be replaced, VIA issued a RFP in 1996. The replacement is called VIA's "Integrated Fleet-Wide Automated Vehicle Location/Communications Control and Data Interchange System," or AVL/CCI. In addition to replacing existing AVL and radio equipment, the comprehensive AVL/CCI system:

- Expands AVL and automated data collection to VIA's paratransit fleet;
- Includes next-stop annunciators and farebox interfaces on all fixed-route buses, automatic passenger counters on 25 buses, and a test of 20 security cameras;
- Includes integration with TransGuide, part of the ITS Model Deployment Initiative (MDI) Program;
- Updates AVL to GPS technology and provides an integrated Geographic Information System (GIS);
- Improves operational information processing capabilities;
- Requires that data transferred between the transit agency and each on-board VLU be accomplished through wireless technology;
- Requires all major components of the AVL/CCI system to be operational for at least 15 years; and
- Incorporates the latest integration standards including TCIP and the SAE J1708-based VAN.

*Current Practices Documented*

In its RFP, VIA provided many details of its transit operation to give bidders a good indication of how it utilizes equipment and personnel. VIA included both positive and negative aspects of its existing AVL and radio system, along with the expectations envisioned for its new system. Based on the information provided, VIA made it clear that it would not procure or pay for a new system that is inferior in any significant way to its present system. VIA also made it clear that it would not pay for a system that failed to provide significant improvements in specific areas including: voice and data communications; data communication throughput; hardware, software and data maintenance; vehicle tracking; passenger counting; schedule adherence determination; and others.

VIA insisted that key components and features of the new system must accept future upgrades and additions without discarding hardware and software investments made under the project. In particular, requirements for open-architecture data networks such as SAE J1708 must be compatible with future ITS-related systems.

VIA's approach of (1) making its objectives known; (2) itemizing each aspect of its transit operation; and (3) identifying the strengths and weaknesses of its existing radio/AVL system is an interesting concept. The approach clearly identifies what VIA expects from the system, and the type of problems that must be avoided.

*Radio and AVL Concerns Disclosed*

Examples of the problems that VIA encountered with its existing radio system include: proprietary interface equipment; replacement parts and equipment were not readily available; coverage area was limited due to dead spots; and the radio's limited capacity for both voice and data transmission.

Problems with VIA's existing AVL system include: proprietary design of computer system; signpost-based system that could only be adapted for fixed-route service; maintenance intensive nature of the equipment; and an increasing number of radio interface failures.

In addition to information provided in the specification, bidders were invited to review details of VIA's current radio/AVL system. Despite the comprehensive nature of its specification, VIA encouraged suppliers to propose alternative approaches if it was more cost effective and efficient to do so.

*Specific Benefits Expected*

VIA's RFP was written to ensure that its new AVL/CCI system would provide several benefits. Concerning the radio system, VIA requested that the newly delivered system have about 50 percent unused capacity at peak operation. Other benefits expected include increased coverage area, dynamic channel assignments, system redundancy made possible by dual repeaters, increased reliability and functionality, and readily available replacement parts. To ensure compliance with future FCC requirements, VIA required bidders to cover parts, labor and materials needed to convert the system to comply with refarming mandates for a period of 15 years.

*Electronic Training Program*

To prepare maintenance personnel for the new electronic technology, VIA started a Vehicle Maintenance Electronic Training Program. Open to all skilled maintenance employees, the program consists of three courses offered at a local college. The three courses include (1) Principals of DC/AC Circuits, (2) Semiconductors, and (3) Digital Fundamentals.

Interested employees are selected for the program based on an interview by VIA management and aptitude tests conducted by VIA and the college. Five employees scoring the highest are selected for the program, which will continue on an ongoing basis.

VIA pays for tuition, books, and up to 12 hours of classroom time per semester. Successful applicants are responsible for study time and maintaining a grade level of B or better. It is interesting to note that VIA's advanced electronics training program is based on ability, not seniority.

## New Jersey Transit Specifies APC-Based Event Recorder

*Background*

New Jersey Transit (NJT) currently uses a signpost-based AVL system to monitor bus location on urban routes in one county. The system provides real-time schedule adherence data to bus supervisors. In the future, signposts installed at each garage will also enable NJT to monitor bus pull-ins and pull-outs.

*Next Phase Planned*

In the next phase of advanced on-board electronic application, NJT is planning to deploy what it calls an Automatic Passenger Counting (APC) and Data Management System. When fully operational, it is expected to be the largest APC system in America. The system, which will monitor passenger boardings at specific locations, is expected to make passenger count and other information more accessible and comprehensible to managers.

Electronic-registering fareboxes currently used by NJT provide service planners with summary data, which include total trip and zone-to-zone ridership information. However, the fare register system does not have the ability to record vehicle location or speed, and as a result, cannot be used to identify peak load conditions or running-time discrepancies — information critical to the scheduling process.

According to NJT, about 340 staff workers would be needed to provide accurate ridership data of the quantity and quality that the new APC system is expected to produce. It will gather time- and location-stamped information, indicating how many passengers get on and off each equipped bus at each bus stop, how many passengers are on board at any given location, and how long it takes to traverse each segment of each bus route at various times of the day.

*APC Details*

Information will be gathered by 170 APC units, rotated among 240 buses equipped to accept the APC equipment. Rotating APC equipment in service will enable NJT to obtain a statistically valid sampling of each route and trip without purchasing APC equipment for each bus. The APC system is controlled by an on-board event recorder, similar to the VLU used in an AVL system. The event recorder will store data generated from the APC system, vehicle speed sensors and other on-board equipment. In addition to passenger-counting activities, the on-board data recorder will store and download interior bus temperatures throughout the day to provide an indication of passenger comfort.

*Wireless Data Downloading*

Data will be automatically downloaded on each equipped bus on a daily basis via short range, wireless RF communications equipment to be installed at each garage. Data will be forwarded to NJT headquarters via the existing wide area office automation network. From there, data will be electronically cataloged, summarized and archived. Together with complementary schedule and revenue data, the APC-generated data will be made available to all departments for analysis and reporting on desktop computers.

APC-equipped buses will be placed in 27 garages, some of which are operated by contracted carriers. Installation on contracted buses will allow NJT to monitor and confirm the activities of contract carriers. Installation and testing of the system will be implemented under a phase-in program to ensure that the final system has been fully proven in a pilot environment prior to full deployment. Assistance in verifying system performance will be provided by the New Jersey Institute of Technology.

NJT's APC system will derive location information from GPS. The existing signpost system will supplement the APC data by monitoring actual headways for all buses, including those not equipped with APCs. In the future, NJT may decide to replace the signpost-based system with GPS technology.

*New Positioning System Test*

As part of its new APC system, NJT will also test 17 Continuous Positioning System (CPS) units. CPS is a new technology that uses a GPS receiver, fiber optic gyro, odometer sensor, and a Kalman-filter processing system to provide extremely accurate vehicle location data. NJT will use this technology in buses traveling through tunnels, and those entering the Port Authority bus terminal to monitor boardings at specific gate locations. Since GPS is not operable inside the terminal, the CPS test will allow NJT to evaluate the accuracy of new location technology for potential applications in the future.

*Double-Stream Door APC Test*

Another element to NJT's procurement is a fully functional Double-Stream Door (DSD) APC Passenger Count Sensor System. Whereas conventional single-stream doors can use a horizontal infrared beam, DSD applications tend to defeat the technology because one set of passengers is boarding while another alights. The DSD approach will use overhead sensors to count boarding and alighting passengers separately.

*Interoperability Essential*

In its specifications, NJT is clear to point out that the new APC system must be interoperable with related elements of its existing data environment. NJT is also requiring a standard, non-proprietary data format for all electronic data transmissions, manual or automatic, between the APC system and the garage support system.

## POTENTIAL RISKS

### Overview

There are potential risks associated with any emerging technology — including the application of advanced electronics to transit buses. Risks can be attributed to a number of factors including faulty hardware and software, insufficient support by vendors, and the inability of agencies to implement the technology. This last factor is one that cannot be overlooked, as perfectly good technology could easily be foiled by those who neglect to operate and maintain it properly.

As the experiences below indicate, transit has not been immune to problems resulting from the application of electronic technologies. According to one official who summarized the implementation of Information Level technologies, it has been "a very difficult birthing process."

Presenting some of the risks associated with Information Level integration allows agencies to consider a broad range of issues before applying the technology. A major concern surrounding the technology is that much of it is being implemented on a stand-alone basis without an overall vision for the future. Speaking at TRB's 1998 Annual Meeting, Dr. Christine Johnson, director of U.S. DOT's ITS Joint Program Office, stated (74):

> "...components are being deployed right and left... But virtually none of it is being integrated... If we don't intervene within the next five years, we will be living with a hodgepodge of non-integratable technology..." Although the comment was directed at the entire ITS effort, the statement also applies to electronic integration at the bus level.

A major obstacle to wide-scale, seamless integration of electronics is a lack of formal standards. The section below examines the lack of standards in specific areas. It also presents some of the difficulties encountered by agencies during the implementation process.

### Lack of Standards

Unlike Drivetrain Integration, Information Level integration occurred before formal standards were developed. As a result, many agencies are already living with the "hodgepodge of non-integratable technology" referred to by Dr. Johnson. Lack of standards is prevalent in virtually every area of Information Level integration. Although efforts are underway to finalize many of these standards, they are not fully developed. Nor have they been fully tested on a industry-wide scale. Examples include (75):

- There are no standards for utilizing Geographic information Systems (GIS). GIS is the foundation for an AVL system — AVL determines the location while GIS provides the reference points for mapping the location coordinates.

- Although more than 70 agencies in North America have deployed or secured funds to implement AVL:

  "... all AVL systems are proprietary, locking agencies into a vendor-specific system. Most AVL systems are not designed to allow for integration with an overall management system. Therefore, expansion to include upgrades or to integrate with an overall management system will be very expensive."

- There are no data communication standards formally adopted by transit to allow for the interoperability and integration of on-board subsystems. (The SAE J1708-based VAN has recently been finalized but is not fully operational or accepted by all agencies.)

- Concerning electronic fare payment systems, all use different technologies and no overall standard exists. (IEEE has been designated to develop standards for transit fare collection.)

- Concerning traffic signal preemption technology, existing communication standards for transmitting data between roadside devices and vehicles are all proprietary. (NTCIP/TCIP is working to develop standard interfaces.)

### Project Delays

Project delays are common with Information Level integration. One agency, realizing the need for improved bus communication and location capabilities, developed a specification and awarded a contract within one year. Due to complications, the system was not accepted until eight years later. Once delivered, the sign-post-based AVL system was already outdated and inadequate for much of the agency's needs. Within a few years, the equipment was no longer being supported by the original hardware and software suppliers, which further aggravated the situation.

### Vendors Abandon Market

There are several examples where vendors have either left the market or merged with other companies, leaving agencies with unsupported proprietary equipment.

### Inadequate Documentation and Training

In some cases, documentation left by the vendor is inadequate and incomplete, which makes it difficult to operate equipment properly. The problem is exacerbated when a vendor leaves the market and there is no way to obtain needed reference material. As a result, it becomes difficult to find and retain programmers that can operate custom-designed software. Additionally, agencies are forced to make patchwork-type modifications or "fixes" to keep equipment operational.

Until agencies prepare their own training syllabus, it becomes difficult to train dispatchers and bus operators adequately. Another consequence of poor documentation is that technicians must rely on their own notes and drawings to make repairs. In some cases, maintenance training was held years before technicians were able to use the information for actual hands-on repairs.

### Increased Maintenance Costs

One agency with a fleet of about 500 buses has seen its annual costs for radio maintenance increase from $75,000 to $325,000 because of its AVL system. The cost of replacing a radio at the same agency has increased from $500 per bus for the old system, to $2,500 per bus for the new system which requires reprogramming.

### Staff Cuts Coincide with Additional Staffing Needs

The capabilities inherent with Information Level electronics not only increases the requirements for overall staffing, but adds responsibilities to existing staff. In some cases, a planned reduction of staffing coincided with the introduction of advanced communication and location technologies that required additional manpower to operate and maintain. As a result, initial problems encountered with the equipment combined with staff reductions produced troublesome consequences. To rectify the matter, a 50% increase in staffing was recommended to adequately support the existing radio/AVL system.

### Bad Press

Agencies should be prepared to deal with local media that may take an interest in new technology applications. While positive press reports can help promote new electronic technologies, negative reports can have serious consequences. As an example, a transit agency was severely criticized by the media for start-up problems encountered by its AVL system. In an article that referenced "Star Wars" technology, the newspaper questioned the need for satellites in outer space to find large buses downtown.

In defense of its AVL system, the agency identified a number of benefits resulting from the technology, including the ability to locate hijacked buses, and costs savings associated with the elimination of traffic checkers. However, after further investigation, the press reported that hijacked buses had not been a significant problem in the past, and that the cost savings had not, in fact, been realized. This led to further criticism in the press.

When promoting the advantages of advanced on-board electronics, agencies need to be prepared with accurate information that clearly substantiates the benefits. Once the benefits can be supported, the technology and its worth to the community can then be shared with the local media.

### New Technology Not as Good

At one agency, a veteran dispatcher revealed that buses appear on the AVL display console only when the operator calls in, or responds to a call. Since most operators cannot see the flashing lights on their display terminal that denote a call, or choose to ignore calls altogether, the dispatcher admitted to never using "that thing anyway." And because street maps used on the computer screen are inaccurate, the dispatcher prefers to use printed bus routes and street maps to help locate buses and give directions.

At another agency, operators requesting communication with the dispatcher were told that the system was designed for a three-minute average wait time. However, the actual average wait time was 15 minutes, with some operators waiting hours to communicate with a dispatcher. Knowing that dispatchers will give in-coming telephone calls priority, some bus operators use pay phones or have purchased cellular phones to communicate with dispatchers. In other cases, operators flag down a local police officer to help with a problem.

### On-Board Equipment Problems

Some agencies reported that the visibility of text messages displayed on the display terminal is poor in daylight conditions. At others, bus operators complained that radio volume is either too high or too low, and the LED lamp that indicates power to the system is too bright. One agency reported that a contract was delayed because the silent alarm feature would not function when the GPS signal was lost.

### Shoddy Retrofit Installations

Several agencies reported that system integrators often contract out equipment installation work to other firms. Due to the high turnover encountered with some of these firms work quality tends to be poor, resulting in malfunctioning equipment and project delays.

### Legal Disputes

There are several on-going legal disputes being fought between equipment suppliers and transit agencies over the integration of advanced electronic systems. This study will not address those disputes. However, readers are encouraged to investigate the disputes on their own in an effort to mitigate potential legal difficulties in the future.

### Other Experiences

- Because the technology is new to transit, many agency personnel are not knowledgeable enough to write specifications that adequately match the capabilities of the technology with agency needs. Several project managers have cautioned: "Be careful, you just might get what you asked for." The implication is that the equipment, while meeting specification requirements, does not address agency needs.

- One agency representative indicated that, due to the competitive nature of transit procurements, some integrators recognize the inadequacies of an agency's specification but choose to ignore them. Once the contract is awarded, the integrator then offers to restore the deficiencies for additional fees.

- In an attempt to apply advanced electronics to their operations, some agencies may be automating inefficiency (i.e., current procedures are inefficient and the technology only serves to automate it).

- System integrators, while understanding the technology, may not be familiar with transit operations and lack the ability to help solve agency problems.

# IMPLEMENTATION GUIDELINES

This chapter begins with a review of the overall findings. It then provides guidance for agencies planning to implement advanced on-board electronics in three bus areas. Guidance for bus transit as a whole is also provided at the chapter's end. Due to the nature of the material, a summary is not provided.

## OVERALL FINDINGS

(1) Advanced bus electronics is an extremely complex, multi-faceted subject. Few in bus transit fully comprehend the many technologies and surrounding issues. Agencies tend to underestimate the level of understanding needed to successfully implement electronic technologies.

(2) The application of electronics to buses is occurring in stages. The first stage applies simple electronics to enhance individual components. Solid-state battery charging is one example. The application of LED exterior lamps is a more recent example. In the next stage, electronics are applied to augment the control of components such as engines, transmissions, HVAC systems, doors, and others.

In the third stage, on-board bus components are integrated to perform more complex functions such as anti-lock braking, climate control, door interlocks, and others. The fourth stage links buses with the transit agency to monitor vehicle location and other aspects of vehicle and operator performance.

(3) The integration of electronic systems has evolved around three bus areas: Drivetrain Level, Electrical Level multiplexing, and the Information Level.

(4) Drivetrain integration and multiplexing are accomplished by the bus builder and delivered to agencies as integral, fully operational systems. Drivetrain components are integrated around open data networks such as SAE J1708/J1587 and J1939. The use of open networks allows components from different manufacturers to be used interchangeably.

(5) Electrical system multiplexing is integrated around proprietary data networks. Despite its proprietary nature, multiplexing does not impact the devices being controlled. For example, agencies can continue to purchase lights and related switches from traditional sources.

(6) Information Level integration is performed by system integrators who typically install equipment as retrofits. The integration, which had been based on proprietary networks exclusively, is beginning to include conformity with the SAE J1708-based vehicle area network (VAN). The majority of installations, however, have been built around "custom" networks and software applications that limit product interchangeability and expansion.

(7) Like the auto industry, the heavy-trucking industry has integrated Information Level components as an essential part of the overall vehicle design. Components and systems pertaining to vehicle location, equipment and operator monitoring, and radar crash avoidance are all integrated around SAE data networks. The standard approach to integration allows end users and truck builders to select from a variety of products.

(8) The ability of the J1708-based VAN to handle on-board Information Level integration in buses is being questioned by some. Among other factors, opponents believe that it is not fast enough to address real-time data transmission. In response, the VAN Committee claims that (1) the radio is the limiting factor, not the J1708 network; and (2) after investigating several approaches found J1708 to be the most appropriate and cost-effective solution for bus applications.

As a voluntary standard, agencies are not required to specify SAE J1708 for Information level integration. Until a preferred standard is accepted on an industry-wide basis, some agencies and suppliers are taking a "wait-and-see" approach.

(9) While the industry decides on an universal approach for on-board integration, the ITS program is working on a national architecture to allow dissimilar elements of ITS (i.e., commercial vehicles, cars, highways, etc.) to exchange data using a similar format. The use of a national architecture is essential to ITS because it permits each transportation mode to use whatever procedure it deems appropriate for on-board data exchange. Standardized interfaces will then "translate" data into a universal electronic language understood by all ITS participants.

(10) To facilitate the integration of dissimilar ITS elements, TEA 21 encourages the adoption of standard data communication procedures and interfaces. Contained in TEA 21 are provisions that may require the use of provisional standards if transportation modes cannot decide on standards of their own.

(11) Experiences associated with advanced on-board integration have been mixed. As mature technologies developed by larger industries, drivetrain integration and multiplexing have provided obvious benefits. For example, multiplexing has streamlined the electrical system, which had become extremely cumbersome and complex. Drivetrain integration has improved driveability and fuel economy, reduced emissions, and made possible two important safety features: anti-lock brakes and traction control.

Benefits derived from Information Level integration are more difficult to quantify. The application is relatively new to transit, comprehensive and objective cost/benefit analyses have not been undertaken, and many of the benefits are hard to quantify (i.e., the impact of AVL on ridership due to the many factors that influence it).

Agencies report several benefits from Information Level integration. They include improved communications, monitoring schedule adherence in real time, use of silent alarms and covert microphones to determine the extent of on-board emergencies, and fare collection data segmented by each transaction.

While benefits are well documented and promoted, many of the negative experiences associated with the technology and transit's ability to apply it properly have been minimized or overlooked. Included are project delays, insupportable equipment, legal disputes, new equipment that does not perform as well as older approaches, increased maintenance costs, and others.

## AGENCY GUIDANCE

Guidance offered here is based on information obtained from transit agencies, systems integrators, product suppliers, and the author's own viewpoint. In addition, several publications were extremely helpful in developing guidance for implementing Information Level technologies (60, 65, 75, 76, 77).

## INFORMATION LEVEL INTEGRATION

Guidance concerning Information Level integration are presented under the following categories:

- Educate Staff
- Identify Current Abilities
- Initiate Basic Training
- Identify Needs
- Establish a Long-Range Plan
- Determine Resource Requirements
- Decide How Much Technology to Take On
- Identify Funding Sources
- Procurement Considerations
- Implementation Considerations
- Specific Technology Considerations

### Educate Staff

The integration of Information Level electronics impacts virtually every level of an agency's operation, making it essential that as many employees as possible gain a working understanding of both the technology and issues involved. The complexity associated with advanced electronic technology and the need to provide training in this area cannot be overstated. Many agencies underestimate the understanding required to successfully implement the technology, and how a lack of knowledge can undermine the best intentions.

The better informed employees are, the better prepared the agency will be to implement technology in an effective and cost-efficient manner. A knowledgeable staff is also more likely to embrace the technology and become part of a team effort to solve technical difficulties and optimize the technology's potential. Collectively, an agency's staff should have an understanding of:

- All aspects of the various technologies including its capabilities, limitations, and costs;
- Staffing requirements needed to procure, operate, and maintain hardware and (especially) software;
- Staffing requirements needed to manage and analyze data generated from the technology;
- Success and failures that others have had with technology implementation, especially from those working with it on a daily basis;
- Background of systems integrators and peripheral equipment suppliers involved with the technology including their financial stability, years of related experience, and locations where the equipment is operational and/or planned; and
- Activities relating to the development of standards including TCIP, VAN, ITS Architecture, TEA 21 provisions, and radio frequency refarming.

While this study serves as a starting point for obtaining an overall understanding of electronic application, other publications address subjects in greater detail. The Reference Section of this study contains a listing of such material. Additional material is also available from APTA, ITS America, and FTA on a continuing basis.

### Identify Current Abilities

In addition to gaining an understanding of advanced technologies, agencies should identify their own abilities with regard to existing electronic applications. Agencies would benefit from knowing:

- How well the staff has implemented, operated, and maintained existing electronic technologies such as destination signs, fareboxes, radios, and electronically-controlled drivetrain components;
- Number of road calls resulting from electrical- and electronic-related failures;
- Competence level of technicians repairing existing equipment; and
- Number of shop comebacks (i.e., repeat failures) resulting from electrical/electronic repairs.

If an agency has difficulty operating and maintaining existing electronic equipment, the problem will only become worse with the application of advanced systems.

### Initiate Basic Training

Before considering new electronic technologies, agencies should improve the skills of those operating and maintaining existing equipment. Doing so will require a commitment of both funding and manpower. The level at which upper management supports basic training will serve as a good indication of its future commitment to training. If management is not willing to allocate the resources needed to enhance basic electronic skills, chances are it will treat advanced technology in a similar fashion.

#### *Maintenance Training*

Unlike mechanical systems where equipment operation can be observed visually, electronics has no moving parts. Most electronic systems use PCs and software programs to diagnose failures, requiring maintenance personnel to have basic computer skills. Diagnostic software programs are structured to find faults at the "lowest repairable level," where the defective part is identified and then replaced with a new or rebuilt unit.

Knowing how to troubleshoot electronic systems and components correctly is extremely important. Without this understanding, technicians tend to change parts at random until finding one that corrects the problem. In many cases, perfectly good parts are replaced unnecessarily, resulting in excessive labor and materials costs. If poor diagnostic skills go unnoticed, these costs are unfairly attributed to the technology — not the agency's inability to repair it correctly.

Before obtaining vendor-specific training for existing products, agencies need to ensure that maintenance personnel have a basic understanding of electronics and how to operate PCs. Vendors can then be called in to provide specific training on locating faults and replacing defective parts. Vendors can also be helpful in accessing the skill level of those working on their products. By inspecting products in the field, reviewing warranty claims, and discussing procedures with maintenance personnel, vendors can help determine skill levels. Vendors can also be helpful in directing training to specific areas.

#### *Operator Training*

Bus operators and their supervisors can easily make or break any technology. Before considering new on-board equipment, provide operators and their supervisors with refresher courses on existing electronic equipment. The refresher courses can also be used to introduce advanced technologies being implemented by other agencies.

Certain operators will shun the responsibilities associated with any new technology. However, informing operators in advance allows them to become familiar with new technology in a gradual manner, making them more likely to offer valuable input prior to equipment procurement. They will also be more receptive to technology that is somewhat familiar to them when initial training on new equipment begins. Conducting primer courses also identifies operators who are more receptive to new technology. They can be helpful in promoting new technology to their peers and in assisting with future training.

### Identify Needs

Before considering specific technologies, agencies should conduct a comprehensive needs analysis to determine exactly where their problems lie, and how goals and objectives of the agency and region can be met. High-tech equipment developed for aerospace and other industries can be very appealing, and has come to symbolize a progressive approach for those applying it. However, implementing new technology just because it is appealing or popular is inappropriate and wasteful. By setting aside the technology and identifying specific problem areas within their organization, agencies can seek appropriate solutions based on need.

All potential solutions to problems, including those not involving new technology, should be considered. Does new technology represent the best approach? Can problems be solved more efficiently with people instead of machines? Can existing equipment be better utilized or enhanced to solve problems? These are some of the questions that must be addressed when seeking solutions to specific problems.

Understanding that it may not be practical or possible to address all problems at once, agencies should prioritize their needs. Doing so will make it easier to create a long-term strategy for applying new technology.

After conducting a needs analysis, New Jersey Transit (NJT) determined that it could benefit from obtaining accurate ridership data to plan service effectively. To obtain this data, the agency considered several approaches before deciding to test a time- and location-stamped APC system. Based on the evaluation, NJT decided to proceed with an APC system before upgrading its existing signpost-based AVL system.

### Establish a Long-Range Plan

After the needs have been identified and prioritized, it is strongly recommended to develop a strategic plan or vision for implementing the various Information Level technologies. Since technologies cut across various modes of transportation and geographic areas, a long-range plan must be developed with other jurisdictions. Up-front strategic planning and coordination should include all affected departments within the agency, including both management and labor. Isolating those who will eventually operate and maintain the equipment from the planning process reduces the likelihood that the technology will be accepted and applied correctly.

Involving all affected agency departments early in the planning process will ensure that resources are fully utilized and department needs addressed. An inclusive, coordinated strategy also identifies the roles that each department will play during the deployment process. Understanding the various roles also allows individuals to move beyond their specific responsibilities to gain a "big picture" look at how the entire system will function.

In addition, combining resources at the start tends to balance the desires of those who may not fully understand all aspects of the technology. General Managers, for example, may not be aware of the technical and staffing requirements of certain technologies they support. Likewise, technical managers may not have a grasp of the legal, financial, and broader issues that must be addressed when implementing technology. Combining the resources of bus maintenance, operators, dispatchers, supervisory staff, procurement personnel, and planners helps to ensure that the technology will be applied correctly and efficiently.

Electronic technologies can be viewed as tools, each with certain capabilities and limitations. Unless these tools are applied properly, they cannot be expected to provide benefits. Having a long-range vision helps to ensure that the tools are applied correctly in a systematic manner to yield specific results. The alternative is a helter-skelter, change-order approach where agencies attempt to add new features randomly.

A building-block approach to implementing technology, organized through a long-range vision, allows agencies to adopt new features as funding and resources become available. Long-range plans should also take into account the life expectancy of each technology. VIA, for example, requires that its new radio/AVL system be operational and supportable for a minimum of 15 years.

*Consensus Building*

Gaining system-wide support for implementing an agency's long-range plan is critical. Consider organizing a steering committee that includes participation from all affected parties, including those outside the agency.

Broad-based support for the plan should include upper management, as well as those who will operate and maintain the equipment. If the entire organization is not committed to the technologies, implementation will be troublesome and many of the benefits inherent with the technology will lie dormant.

Identifying articulate, high-level agency executives and board members who support the project will make it easier to obtain project approval. Supportive executives can also serve to convince the community and agency employees that the technology is worthwhile.

Interviews conducted at agencies where broad-based support was not obtained produced an "us-against-them" attitude. Bus operators were critical because they were expected to use equipment that turned out to be ergonomically unsound. Mechanics, alienated from the planning process, viewed the equipment as "additional work."

### Determine Resource Requirements

Once a long-range strategy has been established, agencies need to determine the resources required to implement each electronic technology identified. Many underestimate the level of staff effort and funding required to implement electronic technology, especially when it involves integration. Contacting and visiting other agencies who have implemented similar technologies will serve as a good starting point. In addition to the project managers, speak with individuals who work with the equipment on a daily basis.

When determining the level of resources needed to implement technology, include the time and costs associated with:

- Educating the staff on the technology and related issues including travel, meeting expenses, literature, and lost productivity time;
- Development of short- and long-term strategies for technology implementation;
- Outside consulting services;
- Procurement activities;
- Capital cost of equipment and software;
- Total number of units being deployed;
- Expected equipment life;
- Travel to successful bidder's facility for acceptance testing and to clarify technical and contractual matters;
- Initial and update training relating to the operation and maintenance of equipment;
- Software development and other enhancements to optimize the equipment as revenue service experience is gained;
- Equipment maintenance and repair;
- Extra labor costs associated with enhanced skill levels needed to operate and maintain equipment; and
- Activities needed to accommodate new developments and enhancements in hardware that will be introduced over time.

### Conduct Cost/Benefit Analysis

As noted earlier, conducting a cost/benefit analysis can be difficult for several reasons. Primarily, advanced Information Level technologies are relatively new to transit, and empirical and comprehensive data with which to support the benefits is not yet available. Many of the technologies, adopted from military and personal electronics, have not yet been proven under the unique demands of a transit environment. Furthermore, there is no forum or industry publication that provides an objective assessment of agency experiences encountered to date.

Although data are limited, and agencies conducting the analysis may have no direct experience with the technology, certain steps can be taken to estimate the costs and benefits for promising technologies. They include obtaining information from agencies experienced with the technology, conducting a literature search, and arranging proof-of-concept demonstrations, followed by pilot evaluations where appropriate. Together, they can provide the data needed to prove or disprove the value of new technologies.

Information gained from agencies that have experiences with technology can be used to verify or refute manufacturer's claims, along with preliminary assumptions made by the agency regarding certain technologies. Obtaining information early in the process can prevent the implementation of a technology that does not function as originally envisioned.

*Assessing the Benefits*

An assessment of potential benefits should be done objectively, putting aside any skepticism resulting from past electronic projects that may have failed. On the other hand, potential benefits from new technology deployments should be estimated with a complete understanding of all factors involved. Assessments should also be carried out in a consistent manner, using uniform guideline and evaluation criteria.

Potential benefits used in the analysis should be defined in terms of costs, including any savings resulting from the technology (e.g., a reduction in fleet size due to improved bus utilization). Other benefits should be valued by their potential to increase revenue, such as increased ridership made possible by improved service, comfort, and convenience.

*Cost Estimations*

The value of benefits calculated through the assessment process represents an estimate of the gross potential benefit only. Costs associated with technology development, implementation, operation, and maintenance must also be determined before conclusions regarding the net value to an agency can be drawn. When final calculations are made, agencies may find that new technologies, while enhancing output, typically do not reduce overall costs (77).

Some of the many aspects associated with estimating project costs have been included in the section above on "Determining Resource Requirements." A more complete procedure for estimating project costs related to advanced electronic technology is provided in Appendix A of a paper prepared by James Kemp of New Jersey Transit (NJT) (76).

Due to the many variables involved, obtaining realistic numbers on all the costs associated with advanced electronic implementation will be difficult. However, according to Mr. Kemp:

> "the single most important aspect of project cost estimation is the development of an inclusive environment in which every department within the organization is routinely consulted regarding the potential impacts of every project, where benefit assumptions are plainly stated and openly reviewed, and in which no input, however unexpected, is discounted by the project sponsors."

## How Much Technology To Take On?

Based on the understanding gained about electronic technologies, the resources needed to support them, estimates made for potential net benefits, and the staff's ability to bring these benefits to fruition, each agency must decide for itself the level of technology that it is capable of handling at one time. Agencies confident with their abilities may want to consider an aggressive approach to implementing technology. Others with limited capabilities should consider placing more emphasis on improving existing electronic skills, and gaining a more complete understanding of the technologies and issues involved. Additional information on implementation is provided later in this chapter.

## Identify Funding Sources

The flexibility offered by ISTEA in funding both highways and transit systems has been extended by TEA 21, which also reauthorized the federal ITS program (63). In addition to allocating up to $110 million in spending annually for ITS research, standards, and operational tests, TEA 21 provides up to $122 million annually for ITS deployments.

Funds from the Congestion Mitigation and Air Quality Improvement (CMAQ) program are also available in non-attainment areas where minimum federal standards for air quality have not been met. CMAQ funds, distributed according to a federal formula, can pay up to 100 percent of project costs that improve transportation-system efficiency, reduce vehicle use or travel, or implement other measures that reduce vehicle emissions (60).

The National Highway System (NHS) legislation allows multi-jurisdictional regions to use up to 10 percent of their highway funds, and up to 10 percent of their transit funds, to create a state infrastructure bank for ITS-related projects. Local governments can use the bank loans to fund projects. NHS also allows local governments to seek private sector partners for ITS projects. Other potential funding sources for transit ITS applications include:

- Surface Transportation Program (STP) funds;
- FTA grants (i.e., Section 3, Section 9);
- State and local grants;
- Privatization projects (i.e., public/private partnerships); and
- Sale or lease of rights-of-way, such as municipal communications equipment mounted on utility poles or embedded in roadways to support other ITS technologies.

In reality, funding sources for both basic transit services and ITS projects are limited (75). Factors include:

- A backlog of traditional, non-ITS projects that compete with ITS for funding;

- Agencies continually need funds to maintain existing buses and purchase new ones; and
- Funding ITS projects tends to be a piecemeal process where funding is secured through several sources, some of which are not available when the project is initiated.

Other factors related to the acquisition of funding include:

- A comprehensive plan helps to secure approval for funding requests;
- Acquiring funding is easier if the agency can secure private sector participation; and
- Practical projects are more likely to receive funding than spectacular ones.

### Procurement Considerations

Computer-controlled components integrated in the Information Level are complex and constantly changing. The microchip, the workhorse of today's computer, doubles in power every 18 to 24 months (60). By 2000, chip manufacturers plan to develop a microchip that will have up to 100 million transistors, capable of performing two billion instructions per second.

Given the long procurement cycles often experienced in transit, rigid specifications that stipulate specific approaches to technology do not lend themselves to the ever-changing world of electronics. The private sector has learned to procure complex computer systems in phases, where specific elements of the technology are proven first before moving on to the next phase. In transit, where funds are not as flexible, the tendency is to think big when it comes to funding computer systems (60). That approach, however, runs contrary to today's computing wisdom.

Also running contrary to electronic equipment procurements are traditional sealed bids where contracts are awarded to the lowest cost, qualified bidder. The emphasis on low bid is appropriate in cases where a minimum level of quality and functionality is acceptable. However, in cases of advanced electronic technologies, the low-bid approach can produce disastrous consequences.

Further complicating procurements is a situation where electronics equipment suppliers have limited experience with transit, and transit has limited experience with electronic applications. This unique condition requires sharing of knowledge by both parties to ensure that equipment is well suited to meet the specific needs of each agency. As noted earlier, several project managers warned of getting exactly what they asked for, although the technology ultimately did not serve the agency's needs.

While agencies cannot overhaul the procurement process, there are certain steps that can be taken to address some of the procurement challenges presented by advanced electronics. They include:

- Review existing procurement rules, regulations, and procedures;
- Involve experienced contract personnel early in the planning process to determine the most cost-effective and appropriate procurement procedure for the project;
- Engage in joint strategic planning with other agencies and jurisdictions to acquire the necessary goods and services to accomplish regional objectives;
- Consider "best value" methods to award contracts in cases where total life cycle cost is a serious consideration, or where qualitative factors such as the vendors' commitment to quality and customer satisfaction are more important than simple adherence to specifications;
- Request information and expressions of interest from potential vendors prior to developing the procurement specification,
- Pre-qualify vendors and products;
- Consider lease-purchase procurements;
- Describe your transit operation in great detail;
- Indicate exactly what you expect the technology to achieve in simple terms; and
- Incorporate emerging standards to ensure product interoperability and expansion for the future.

#### *Request for Information, Expressions of Interest*

A request for information prior to developing procurement specifications can be very useful in obtaining information on planned technology applications. This is essential if agencies need to improve their understanding of technologies that they are unfamiliar with.

Agencies should also consider issuing a request for expression of interest (EOI) to identify potential suppliers in advance. As a pre-screening step, the EOI can serve to separate those vendors with experience from those not actively engaged in the type of technology application being sought.

### *Best Value Contracts*

Each procurement method has its place when seeking electronic technologies. Before choosing one, however, agencies should determine if it is appropriate to accept:

- Any product that meets a minimum level of quality and functionality, or
- An overall "best value" solution, where something significant can be gained by paying more for a superior product, service, or vendor relationship.

When a minimum level of quality and functionality is acceptable, such as purchasing off-the-shelf hardware or a known commercial software package, the one-step invitation for bid (IFB) is appropriate. In cases where minimum quality and functionality are required, but the product cannot be specified without input from vendors, a two-step IFB is suitable.

When the technology is more complex, however, alternatives to the low-bid approach must be regarded. A request for proposal (RFP) procedure is more appropriate in cases where the agency may receive additional value for additional costs, where life cycle costs are a serious consideration, or where commitment to quality and customer satisfaction are important.

The RFP is especially useful because it allows bidders to propose whatever products might provide the specified outcome. In the area of advanced electronics where agencies may not understand all technology implications, this aspect of the RFP can be valuable.

### *Pre-Qualification*

Regardless of the procurement method chosen, agencies should seriously consider pre-qualifying firms and products. Pre-qualification can include evaluation of sample materials, product demonstrations, pre-award surveys that look beyond product samples to gain a better indication of a vendor's capabilities, and prior experience with similar projects. Pre-qualification evaluations should assess:

- Ability of the vendor to produce products as specified;
- Likelihood that the vendor will deliver products of acceptable quality throughout the contract period; and
- Likelihood that the vendor will provide necessary product support following the procurement.

A formal documentation process is needed for evaluating each pre-qualification criterion.

### *Non-Competitive Procurement*

Non-competitive or sole source contracting is permitted only in limited circumstances. Situations vary from state to state, but typically include cases where agencies require a product or service immediately, the purchase does not exceed a specified dollar amount, and when only one source of supply is available. Concerning advanced electronic applications, sole source procurements become necessary to supplement existing systems designed around a proprietary architecture where equipment is limited to a single supplier. (As described below, an open system architecture encourages product interchangeability and prevents sole source procurements).

### *Lease-Purchase Procurements*

Agencies should also consider a lease-purchase procurement where provisions for operational support, preventive maintenance, and repair are all included in the procurement and paid with capital funds. An alternative is to specify vendor-provided support for a specified period, such as the warranty period or the intended lifetime of the product.

### *Describe Your Operation in Detail*

At a time when many system integrators are not thoroughly familiar with transit, it becomes advantageous to include a complete description of your operation in the bid document. In its RFP, VIA provided bidders with a detailed account of how it utilizes both equipment and personnel. The information allowed bidders to gain an understanding of the operating environment. It also enabled them to suggest more efficient approaches to solving problems, approaches that VIA may have overlooked or been unaware of.

### *Define Objectives and Expectations*

In its specification, Milwaukee County Transit System defined three very explicit objectives for its CAD/AVL system. The objectives were used to accept the system, and served as the yardstick for measuring the project's success.

Using its past experience with a signpost-based AVL system, VIA listed exactly what it expected from its next-generation, GPS-based AVL system. Based on the information provided in the RFP, VIA made it clear that it would not pay for any system that failed to meet those expectations.

The technical specification issued by the San Joaquin RTD (SMART) in Stockton, California, is a good example of where system expectations are identified in simple terms. For instance, SMART requires that an information operator using the AVL system will be able to respond to questions such as: When is the next bus scheduled past Point A?; How do I get from Point A to Point B?; How do I get back?; etc. The direct, simple-language approach gives bidders a clear indication of what the agency expects to gain from the technology.

*Adopt Open System Architecture*

It is important that the procurement of on-board advanced electronic systems include open standards for data exchange. Open standards provide flexibility by allowing products made by different manufacturers to be used interchangeably.

Conversely, proprietary standards restrict access to the data network, usually to the company that developed the standard. When agencies are locked into a proprietary standard, they are forced to accept whatever performance the system delivers. They must also endure whatever treatment they receive from the vendor until the entire system can be replaced.

Agencies should require potential vendors to provide a copy of the data interface standard(s) being proposed. They should also require vendors to identify specific components and subsystems that will be restricted to certain suppliers.

Standards are open when documentation is available to the public for free or at low cost. Another indication of openness is whether the standard is maintained by a Standards Development Organization such as IEEE, SAE, ITE, and AASHTO. Appendix A of the U.S. DOT's ITS Deployment Guidance lists the major standards that should be considered when deploying ITS technologies (75).

The specific standard currently being developed for on-board Information Level data exchange for bus applications is the vehicle area network (VAN), which is based on a modified version of SAE J1708/J1587. Examples of agencies specifying its use include Houston Metro, VIA, SMART, and NJT.

Other standards effecting on-board equipment include TCIP, the interface standard being developed to exchange data in common format between the bus and transit agency. The standard being developed to exchange data between the transit agency and other ITS elements is NTCIP. Chapters 5 and 6 of this study contain additional information on the various SAE standards, the VAN network developed from them, and TCIP/NTCIP.

Another consideration for implementing standard data networks is TEA 21 provisions that may require provisional standards on transportation sectors if they cannot develop their own.

**Implementation Consideration**

Once an agency selects a vendor for Information Level technologies, there are certain implementation aspects that should be considered. They include:

- Avoid change orders, or what one agency refers to as "feature creep," where agencies continually add new features during the implementation phase as they discover new applications. Remaining focused on the task at hand also keeps the vendors focused;
- Plan to make several trips to visit vendors to ensure the project is on time and running smoothly;
- Expect delays and initial teething problems with equipment deployment. Be prepared to "baby-sit" the system for a while to get the bugs worked out. Problems are to be expected when a product moves from a laboratory environment to revenue service;
- Expect to incur additional costs and staff time associated with debugging and upgrading software, which is evolving on a continuous basis. Agencies must learn to be patient when it comes to software glitches; and
- Be prepared to cancel certain aspects of the deployment if, during the implementation phase, you discover some aspect that is not worth pursuing.

The following section address two additional implementation considerations:

- Phased implementation and testing; and
- Staffing and training.

***Phased Implementation and Testing***

Due to the complexity involved with Information level integration, agencies should consider using a phased implementation approach. The approach can be used in two ways:

(1) To become familiar with a limited number of applications before expanding technology to the entire fleet; and

(2) To test equipment in stages, verifying compliance in one stage before proceeding to the next.

*Figure 9-1* *Classroom display of on-board Information Level equipment for training purposes.*

Applying technology to a limited number of buses gives operations and maintenance personnel time to become familiar with new technology. It also allows the agency to work out initial teething problems on a small scale before implementation begins on the entire fleet. Limited applications can also be helpful in evaluating the effectiveness of certain technologies without making large investments.

Phased implementation can also be useful in ensuring equipment functionality. As indicated in Chapter 7, Milwaukee County Transit Ssytem's RFP called for a three-phase acceptance test where specific elements of its AVL system were proven in stages before the vendor could proceed to the next phase and get paid.

In its specification, VIA established a detailed six-tier approach to technology implementation, which included specific testing requirements for each tier. VIA is also withholding 50 percent of the contract payment until the final stage has been completed.

*Staffing and Training*

Implementing advanced electronics typically results in increased staffing levels, and requires existing personnel to take on additional responsibilities. Agencies need to consider the additional staffing requirements, and determine how it will attract and keep computer programmers, network administrators, and electronic technicians. For complex technology integrations, agencies should consider a systems manager with a "big picture" approach to technology implementation.

Training provided by the vendor should be structured for maximum effectiveness. Complete documentation on all aspects of the equipment is essential to ensure that the agency can continue training once the vendor completes its responsibilities. Agencies should considering training a set of its top employees to serve as trainers, also getting them to become "cheerleaders" for the new technology.

Classroom training for bus operators and supervisors can be enhanced with a mockup of actual components mounted on a tabletop, allowing them to become familiar with the equipment in a more relaxed environment. Figure 9-1 shows a classroom display of typical on-board equipment consisting of an operator's handset, speaker, display terminal, covert microphone switch, radio, and vehicle logic unit.

Classroom size should be limited to about 10 individuals. Follow-up training is recommended after one year as a refresher course, and to verify that operators are using the equipment properly.

Agencies should consider obtaining interactive training videos and similar aids to assist with equipment instruction. Additionally, video taping of vendor-supplied training can be useful in the future as a fall back to ensure that training continues as originally intended. Avoid conducting training too far in advance of receiving equipment, as students will easily forget what they learned if the training is not applied immediately.

As indicated earlier, maintenance personnel need to be computer literate and thoroughly familiar with all aspects of the equipment as quickly as possible. They should also attend operator/supervisor courses to become familiar with the equipment's operation. As with operator training, classroom size should be kept small, complete documentation is absolutely essential, videos of vendor training should be made for reference, and hands-on training should take place just before the equipment arrives at the agency.

## Specific Technology Considerations

### *Radio*

There are capacity tradeoffs that must be considered when using radios for both voice and data transmission. Conventional and trunked radio systems can handle both voice and data; conventional analog is the least expensive and easiest to maintain. It does not, however, make efficient use of all available channels.

A trunked radio makes efficient use of channels, but requires a dedicated control channel and more maintenance. Additionally, the call set-up time inherent with trunking does not lend itself to short bursts of data typically transmitted in bus applications. As a result, many trunked systems operate in conventional mode when transmitting data, switching to channel trunking when voice communication is requested. Doing so causes the data channel to become disconnected.

To transmit voice and data simultaneously, separate radios can be used. While providing greater throughput, the approach is expensive as two sets of radios must be purchased and maintained for each bus.

Without two sets of radios, a primary consideration regarding radio communication is the average amount of time needed to initiate voice and data messages. As noted in Chapter 8, bus operators at one agency found it quicker to use telephones instead of their radios. To avoid this scenario, SMART specified the nominal time for each message type in its RFP. For instance, routine calls shall be initiated in an average of 10 seconds.

Another radio consideration involves refarming to narrower frequency bands. Most analog radio systems operating on 25 KHz can be reprogrammed to operate on a 12.5 KHz bandwidth. However, if the FCC mandates the narrower 6.25 KHz bandwidth, it is expected that digital radios will be required. Although more complex and expensive than analog, digital systems have certain advantages, including superior voice quality. Agencies should keep abreast of refarming activities. In its technical specifications, VIA required the vendor to cover parts and labor needed to comply with refarming mandates for a period of 15 years.

Other radio considerations include:

- Providing maintenance access to equipment for adjustments and diagnostic procedures;
- Interface with VLU, GPS, AVL and antenna;
- Environmental shock, dust, vibration, salt, and water intrusion;
- Mounting location; and
- Noise filtering from fluorescent lighting and other electrical/electronic devices.

### *AVL*

The trend in AVL technology is toward the "smart bus" concept where the vehicle itself determines its location and adherence to established schedules, reporting only exceptions to central control. Determining vehicle location and schedule adherence requires integration with several key on-board systems including the radio, operator's display terminal, VLU, and GPS. Although AVL suppliers specialize in systems integration, agencies must have a clear understanding of what they want the integration to provide.

GPS has become the location technology of choice for transit AVL applications (8). Knowing that GPS signals can become degraded, agencies should consider the use of additional technologies to supplement GPS such as differential GPS, odometer interface, dead reckoning, door interface, and signposts mounted in areas of poor GPS reception. Another consideration is selecting a method to transfer large data files to and from the bus with minimal manpower requirements.

An additional consideration for AVL is that accurate, up-to-date inventory and maintenance of the agency's route network is essential. To use the digital maps and systems that depend on them effectively, the distances and directions of each route must be maintained precisely and accurately. If the route should change, it must be remeasured to keep all AVL functions working smoothly.

Since AVL typically serves as the link to the transit agency and beyond, agencies must also consider the compatibility of on-board data communication with the TCIP program. TCIP is transit's communications connection to the ITS infrastructure. Agencies deploying on-board systems without considering TCIP are asking for trouble.

The interface between SAE J1708 and TCIP is currently being addressed. In general, the communications configuration served by both are different (78). The key difference between them is that TCIP uses a master-slave or unbalanced configuration, while J1708 supports a peer-to-peer or balanced configuration. Despite the differences, the two networks can still exchange data.

The TCIP Committee is recommending a gateway protocol, where an external device will convert data from J1708 to TCIP and visa versa. It is highly recommended that agencies follow the activities related to both TCIP and VAN. Agencies should also become familiar with the NTCIP program, which serves as the overall data communications link to ITS (65).

## DRIVETRAIN INTEGRATION

Although drivetrain integration is accomplished by the bus builder and delivered as an integral system, there are certain steps that agencies can take to improve the operation and maintenance of drivetrain components. Agencies should consider:

- Purchasing software packages from engine manufacturers that provide additional data on drivetrain performance;
- Using the data to maximize fuel economy and brake lining life by optimizing brake balance, retarder application, and shift points;
- Sharing drivetrain data with component manufacturers to solicit their input on maximizing drivetrain efficiency;
- Sharing data such as hard braking and acceleration applications with the operations department so they can retrain operators to improve passenger comfort;
- Using RF links to transmit performance data such as fuel economy, mileage, mechanical fault codes, essential operating temperatures, and other indicators when the bus enters the facility or during service line inspections;
- Integrating drivetrain components with a central microprocessor used for AVL or next-stop annunciator functions as a way of collecting data to one location for real-time monitoring, or for review at a later time;
- After rebuilding, ensure that SAE J1939 compliant drivetrain components are returned to buses equipped with ABS or traction control. (Older engines and transmissions not compatible with SAE J1939 will not function properly in these buses); and
- Obtain electronic training from drivetrain component suppliers and/or the bus builder for maintenance personnel.

## ELECTRICAL MULTIPLEXING

Like drivetrain components, electrical system multiplexing is integrated, installed, and delivered as an integral system by the bus manufacturer. However, certain steps can be taken to ensure efficient operation:

- During pre-build meetings with the bus builder, make a final determination as to the electrical features that will be incorporated into the bus (it is easier and less expensive to make changes before buses are delivered);
- Identify features that the bus builder has offered to other agencies to determine if any would be beneficial to your operation;
- Consider features such as engine starter timer to prevent starter overheating, additional lamps to improve visibility, automatic retarder reactivation when the bus is first started, door interlock functions, and others;
- Keep abreast of new multiplexing developments being introduced, potential applications of SAE J1939 to handle power control functions, and new cabling requirements of SAE J1708/VAN that handle both power and data;
- Obtain a recommendation for the type and quantity of diagnostic tools required to troubleshoot multiplexed systems, along with a spare parts recommendation;
- Obtain adequate maintenance training on diagnostic procedures;
- As with any on-board electronic system, determine procedures for electric welding on the bus to protect sensitive equipment;
- Although laptop computers are typically used to diagnose system faults, consider mounting a full-size PC on a moveable cart. Laptop PCs are prone to dropping, while full-size PCs are more substantial and typically cost less;
- Decide if you want the capability to make the software changes needed to add new electrical functions, or if you want the bus builder do it for you. If you desire the capability, determine the type of equipment needed, level of training required, and how many staff members will be trained to make these changes; and

- Keep a current record of all programming changes, and initiate electrical system changes to all buses as quickly as possible to prevent different electrical configurations in the fleet.

### INDUSTRY GUIDANCE

Based on the findings, the following guidance is offered to the industry at large:

- Due to the complex nature of the technology, the industry should conduct detailed workshops, issue publications, and initiate other activities that promote the understanding of advanced bus electronics in simple terms. The industry also needs a forum to address all aspects of the technology, including related experiences and issues in an open and objective manner;
- Despite the small market size, bus builders should take a more active role with regard to incorporating Information Level equipment into the overall vehicle design as is done in the automobile and trucking industries. Provisions should be made to accommodate fare collection equipment, VLU, radio, operator's display terminal, interior displays, data network cabling, next-stop annunciators, and other equipment;
- The industry should embrace a suitable on-board data exchange standard for Information Level integration. The controversy over the SAE J1708-based VAN must be resolved as quickly as possible, especially with TEA 21 provisions that may mandate standards if transportation sectors are unable to do so;
- The industry should decide how data, standardized to a TCIP format, can be used to benefit all agencies collectively. Standardized data formatting provides an excellent opportunity for agencies to exchange several performance measures including on-time performance, road calls, performance from specific components, fuel economy, idle time, wheelchair lift deployment times, interior temperatures, and others;
- Transit should obtain more "organizational horsepower" to help move electronic integration along. Except for a limited number of volunteers trying to develop standards and sort through the issues, the majority appear to be taking a wait-and-see approach. Those actively involved with the process tend to issue papers and reports that are complex and speak "over the heads" of those who will operate and maintain the equipment. Those taking a wait-and-see approach are possibly hoping for other organizations to address the issues.

  The bus industry as a whole should become more involved in this very complex area that has the potential to offer many benefits. However, if not properly applied, the technology also has the potential to introduce a level of complexity that the industry is unable to handle;
- Establish a peer review panel comprised of experienced bus transit representatives to review and assist transit agencies during planning and implementation phases; and
- The industry should consider expanding "White Book" specifications to standardize electronic integration. An ideal approach to on-board integration duplicates what is already taking place in the trucking industry. In trucking, the data cable, plug-in receptacles for individual components, and the communication protocol that on-board electronic components use to communicate with one another have all been standardized.

  This approach would allow agencies to specify individual components based on performance and special feature considerations. It would also allow components to be easily moved from one bus to another.

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# ACRONYMS AND ABBREVIATIONS

| | |
|---|---|
| AATA | Ann Arbor Transportation Authority |
| ABDS | Automated Bus Diagnostic System |
| ABS | Anti-Lock Brake System |
| ADA | Americans With Disabilities Act |
| ADB | Advanced Design Bus |
| AOS | Advanced Operating System |
| APC | Automatic Passenger Counters |
| APTA | American Public Transit Association |
| APTS | Advanced Public Transportation Systems |
| ARTS | Advanced Rural Transportation Systems |
| ASR | Anti Spin Regulation |
| ATA | American Trucking Association |
| ATC | Automatic Traction Control |
| ATIS | Advanced Traveler Information Systems |
| ATMS | Advanced Transportation Management Systems |
| ATTB | Advanced Technology Transit Bus |
| AVCS | Advanced Vehicle Control Systems |
| AVL | Automatic Vehicle Location |
| CAD | Computer Aided Dispatch |
| CAN | Controller Area Network |
| CARB | California Air Resources Board |
| CDPD | Cellular Digital Packet Data |
| CNG | Compressed Natural Gas |
| CPS | Continuous Positioning System |
| CTA | Chicago Transit Authority |
| CVO | Commercial Vehicle Operations |
| DC | Direct Current |
| ECM | Electronic Control Module |
| DGPS | Differential Global Positioning System |
| DOT | Department of Transportation |
| DUETS | Demonstration of Universal Electric Transportation Subsystems Consortium |
| EPA | Environmental Protection Agency |
| EEPROM | Electronically Erasable Programmable Read Only Memory |
| EMI | Electro-magnetic Interference |
| EOI | Expression of Interest |
| EPROM | Electronically Programmable Read Only Memory |
| ERTICO | European ITS-related activities |
| FCC | Federal Communication Commission |
| FHWA | Federal Highway Administration |
| FMVSS | Federal Motor Vehicle Safety Standards |
| FRA | Federal Railway Administration |
| FTA | Federal Transit Administration |
| GIS | Geographic Information System |
| GPS | Global Positioning System |
| GVWR | Gross Vehicle Weight Rating |
| HOV | High Occupancy Vehicle |
| HVAC | Heating, Ventilation and Air Conditioning |
| IC | Integrated Circuit |
| ID | Identification |
| IEEE | Institute of Electrical and Electronic Engineers |
| IFB | Invitation for Bid |
| I/O | Input/Output |
| ISO | International Standards Organization |
| ISTEA | Intermodal Surface Transportation Efficiency Act (1991) |
| ITS | Intelligent Transportation Systems |
| IVHS | Intelligent Vehicle Highway Systems |
| JPO | Joint Program Office |
| LACMTA | Los Angeles County Metropolitan Transportation Authority |
| LED | Light Emitting Diode |
| MCTS | Milwaukee County Transit System |
| MDI | Model Deployment Initiative |
| MID | Message Identification |
| NHTSA | National Highway Traffic Safety Administration |
| NJT | New Jersey Transit |
| NTCIP | National Transportation Communications for ITS Protocols |
| NYCT | New York City Transit |
| OBD | On-Board Diagnostic |
| ODVA | Open DeviceNet Vendor Association |
| OEM | Original Equipment Manufacturer |
| OSI | Open Systems Interconnection |
| PA | Public Address |
| PC | Personal Computer |
| PCMCIA | Personal Computer Memory Card Industry Association |
| RAM | Random Access Memory |
| RF | Radio Frequency |
| RFI | Radio Frequency Interference |
| RFP | Request for Proposals |
| ROM | Read Only Memory |
| RP | Recommended Practice |
| RPM | Revolution per Minute |
| RT | Remote Terminal |
| SA | Selective Availability |
| SAE | Society of Automotive Engineers |
| TEA 21 | Transportation Equity Act for the 21st Century |
| TCIP | Transit Communications Interface Profiles |
| TCN | Train Communications Network |
| TCRP | Transit Cooperative Research Program |
| TPU | Ticket Processing Unit |
| TMC | Truck Maintenance Council |
| TRB | Transportation Research Board |
| VAN | Vehicle Area Network |
| VCR | Video Cassette Recorder |
| VDV | Verband Deutscher Verkehrsunternehmen |
| VERTIS | Asian ITS-related activities |
| VLU | Vehicle Logic Unit |
| VMC | Vehicle Management Computer |
| VMS | Vehicle management System |
| WSTA | Winston-Salem Transit Authority |

# APPENDIX A SITE VISITS AND TELEPHONE CONTACTS

## *SITE VISITS*

### Transit Agencies

Ann Arbor Transportation Authority
Chicago Transit Authority
DART - Dallas Area Rapid Transit
Houston Metro
Los Angeles County MTA
Milwaukee County Transit System
MTA New York City Transit
New Jersey Transit
Orange County Transportation Authority
Phoenix Transit System
San Diego Transit Corporation
VIA Metropolitan Transit - San Antonio

### Organizations

Allen-Bradley
American Public Transit Association
Federal Transit Administration
I/O Controls Corp.
ITS America
Jevic Trucking
New Flyer of America Inc.
Northrup Grumman Corp.
Orbital Sciences Corp.
Raytheon Company

## *TELEPHONE CONTACTS*

### Transit Agencies

Corpus Christi RTA, Texas
MARTA, Atlanta
Mass Transit Administration of Maryland
MTA, Flint, MI
MTA Long Island Bus
San Joaquin RTD
Winston-Salem Transit Authority

### Organizations

American Trucking Association
Amerex Corp.
Armstrong Consulting
Cambridge Systematics
C.E. Niehoff & Co.
Clever Devices Ltd.
Cummins Engine Company
Delphi Packard Electric Systems
Detroit Diesel Corp.
Dialight
Digital Recorders Inc.
EG&G Rotron
Frieghtliner Trucks
GFI GENFARE
LSB Technology
LTK Engineering Services
Luminator
Marathon Coach
Thomas J. McGean
Meister Electronics LC
Mentor Engineering Inc.
Meritor WABCO
MKF Inc.
Neoplan USA Corp.
NovaBUS
Orion Bus Industries
Prima Facia Inc.
Rockwell Avionics & Communications
S&A Systems
Telephonics Corp.
TVX Inc.
Vapor Corp.
Verband Deutscher Verkehrsunternehmen (VDV)
Voith Transmissions
ZF Industries

# APPENDIX B THE SEVEN OSI LAYERS AND RELATED FUNCTIONS

| Layer | Function |
|---|---|
| **Application** | Provides the interface from applications and users to the OSI environment. This layer also provides management functions to support a distributed system architecture. |
| **Presentation** | Formats the data (i.e., ASCII). |
| **Session** | Maintains dialog between communication devices. |
| **Transport** | Provides reliable end-to-end data transmission. |
| **Network** | When a network consists of subsystems indirectly connected to each other, this layer switches and routes the data to a subsystem connected to a physically different cable. |
| **Data Link** | Provides the interface between the actual cable and data exchange between devices on the same medium. This layer contains the functions t hat determine source and destination identifiers. It also activates, deactivates and maintains communication over the data network. |
| **Physical** | Defines the requirements for interfacing to a cable. It allows detection and generation of signals in the proper bit format in order to receive and send messages onto the cable. |

# APPENDIX C SAE J1939 DOCUMENTS

| Document Code | Abbreviated Document Titles/ Descriptive Names |
|---|---|
| **J1939** | Recommended Practice for Serial Control and Communications Vehicle Network (Class C) |
| **J1939/01** | Truck and Bus Applications |
| **J1939/11** | Physical layer - 250k bits/sec., Shielded twisted pair |
| **J1939/12** | Physical layer - 250k bits/sec., Twisted quad |
| **J1939/13** | Off-Board Diagnostic Connector |
| **J1939/21** | Data Link Layer |
| **J1939/31** | Network Layer |
| **J1939/71** | Vehicle Application Layer |
| **J1939/72** | Virtual Terminal |
| **J1939/73** | Application Layer - Diagnostics |
| **J1939/81** | Network Management Protocol |

The **Transportation Research Board** is a unit of the National Research Council, which serves the National Academy of Sciences and the National Academy of Engineering. The Board's mission is to promote innovation and progress in transportation by stimulating and conducting research, facilitating the dissemination of information, and encouraging the implementation of research results. The Board's varied activities annually draw on approximately 4,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation.

The National Academy of Sciences is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Bruce M. Alberts is president of the National Academy of Sciences.

The National Academy of Engineering was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. William A. Wulf is president of the National Academy of Engineering.

The Institute of Medicine was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Kenneth I. Shine is president of the Institute of Medicine.

The National Research Council was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purpose of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Bruce M. Alberts and Dr. William A. Wulf are chairman and vice chairman, respectively, of the National Research Council.

Abbreviations used without definitions in TRB publications:

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| AASHO | American Association of State Highway Officials |
| AASHTO | American Association of State Highway and Transportation Officials |
| ASCE | American Society of Civil Engineers |
| ASME | American Society of Mechanical Engineers |
| ASTM | American Society for Testing and Materials |
| FAA | Federal Aviation Administration |
| FHWA | Federal Highway Administration |
| FRA | Federal Railroad Administration |
| FTA | Federal Transit Administration |
| IEEE | Institute of Electrical and Electronics Engineers |
| ITE | Institute of Transportation Engineers |
| NCHRP | National Cooperative Highway Research Program |
| NCTRP | National Cooperative Transit Research and Development Program |
| NHTSA | National Highway Traffic Safety Administration |
| SAE | Society of Automotive Engineers |
| TCRP | Transit Cooperative Research Program |
| TRB | Transportation Research Board |
| U.S.DOT | United States Department of Transportation |